Journal

WATER POLLUTION CONTROL FEDERATION

ANNUAL CONVENTION ISSUE

Industrial Wastes in Milwaukee—Ernest

Sludge Reaeration—Haseltine

Pulp Wastes and Fish—Fujiya

Foam Fractionation—Eldib

Wastewater Chlorination—Heukelekian and Faust

Digester Cleaning—Garno

34th ANNUAL MEETING

Auditorium—Arena and Hotel Schroeder

October 8–12, 1961

Program—Page 1001

SEPTEMBER 1961

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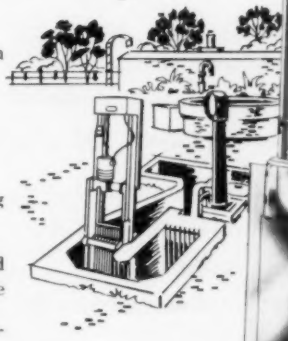

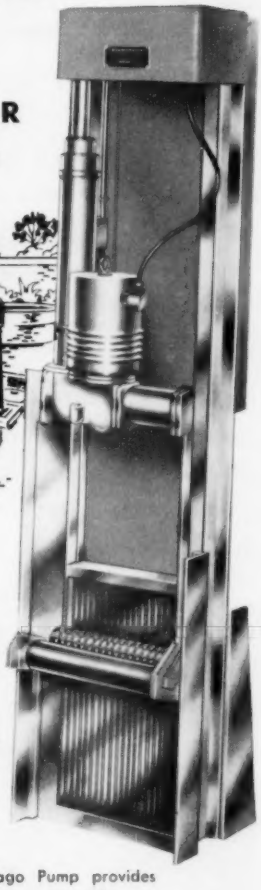

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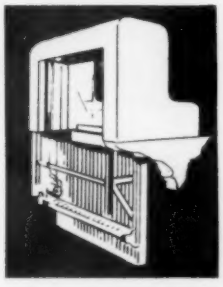

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Volume 33 | September 1961 | Number 9

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EDITORIAL AND EXECUTIVE OFFICES: 4435 Wisconsin Ave., N.W., Washington 16, D. C. Send all manuscripts, advertising copy, subscriptions, address changes, etc., to this address. JOURNAL WPCF is published monthly by the Water Pollution Control Federation at Prince & Lemon Sts., Lancaster, Pa.

SUBSCRIPTION RATES: Members of local associations affiliated with the Federation: $8.00 per calendar year. All others, U. S. and Canada: $10.00 per calendar year; other countries, $11.50 per calendar year. Single copies: U. S.: $1.25 each; other countries: $1.50 each.

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REFERENCE SERVICE: JOURNAL of the WATER POLLUTION CONTROL FEDERATION is indexed regularly by *Industrial Arts Index* and *Engineering Index*. Microfilm copies of this JOURNAL may be procured from University Microfilms, Ann Arbor, Mich. This service is limited to regular subscribers only.

Library of Congress Catalog Card Number: 42-19992.

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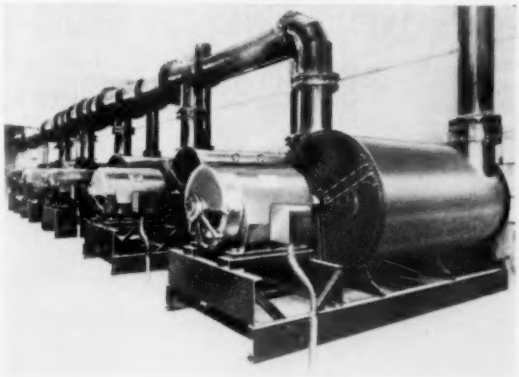

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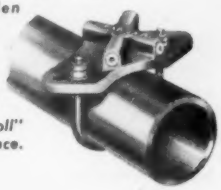

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Association *	*Date*	*Place*
Germany	Sept. 12–16	Hamburg, Germany
South Dakota	Sept. 20–22	Sheraton Hotel, Rapid City
Missouri	Oct. 1–3	Kentwood Arms Hotel, Springfield
Rocky Mountain	Oct. 2–4	La Katchina Hotel, Taos, N. Mex.
North Dakota	Oct. 4–6	Gladstone Hotel, Jamestown
Canada	Oct. 22–25	Sheraton-Mt. Royal, Montreal, Quebec, Canada
Pacific Northwest	Oct. 25–28	Hotel Winthrop, Tacoma, Wash.
Florida	Oct. 29–Nov. 1	Cherry Plaza Hotel, Orlando
New England	Nov. 1–2	Northampton Hotel, Northampton, Mass.
Nebraska	Nov. 8–9	Hotel Lincoln, Lincoln
South Carolina	Nov. 10	Richland County Health Center, Columbia
North Carolina	Nov. 13–15	George Vanderbilt Hotel, Asheville
Indiana	Nov. 15–16	Hotel Washington, Indianapolis
Oklahoma	Nov. 27–Dec. 1	Oklahoma State University, Stillwater
Louisiana	Mar. 14–16, 1962	Louisiana State University, Baton Rouge
Kansas	May 2–4	Lassen Hotel, Wichita
Arizona	May 3–5	Pioneer Hotel, Tucson
Michigan	May 21–23	Park Place Hotel, Traverse City
Central States	June 20–22	Hotel Duluth, Duluth, Minn.

* See preceding left-hand page for full name.

THIRTY-FOURTH ANNUAL MEETING

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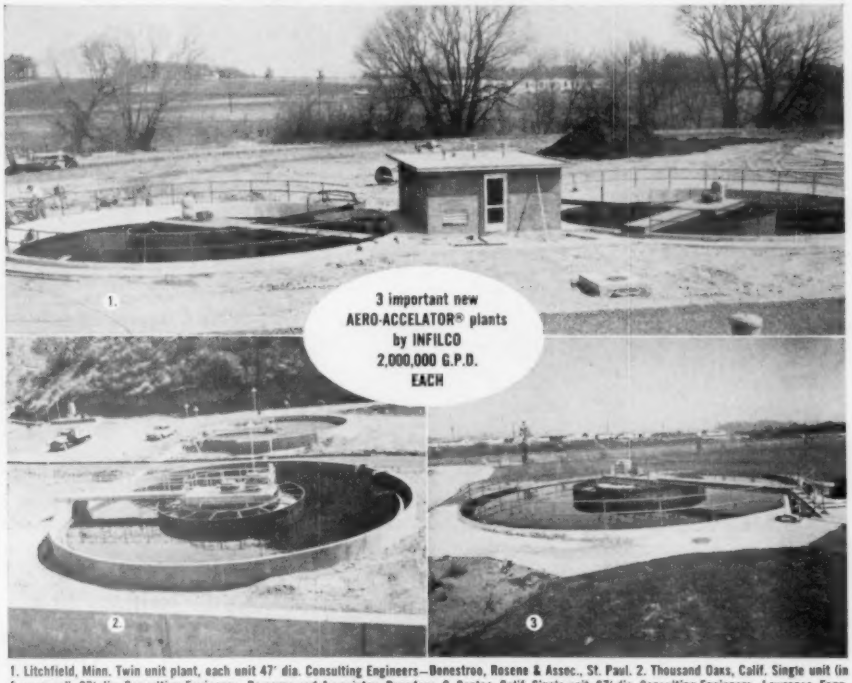

1. Litchfield, Minn. Twin unit plant, each unit 47' dia. Consulting Engineers—Bonestroo, Rosene & Assoc., St. Paul. 2. Thousand Oaks, Calif. Single unit (in foreground), 67' dia. Consulting Engineers—Pomeroy and Associates, Pasadena. 3. Santee, Calif. Single unit, 67' dia. Consulting Engineers—Lawrence, Fogg, Florer & Smith, La Mesa, Calif.

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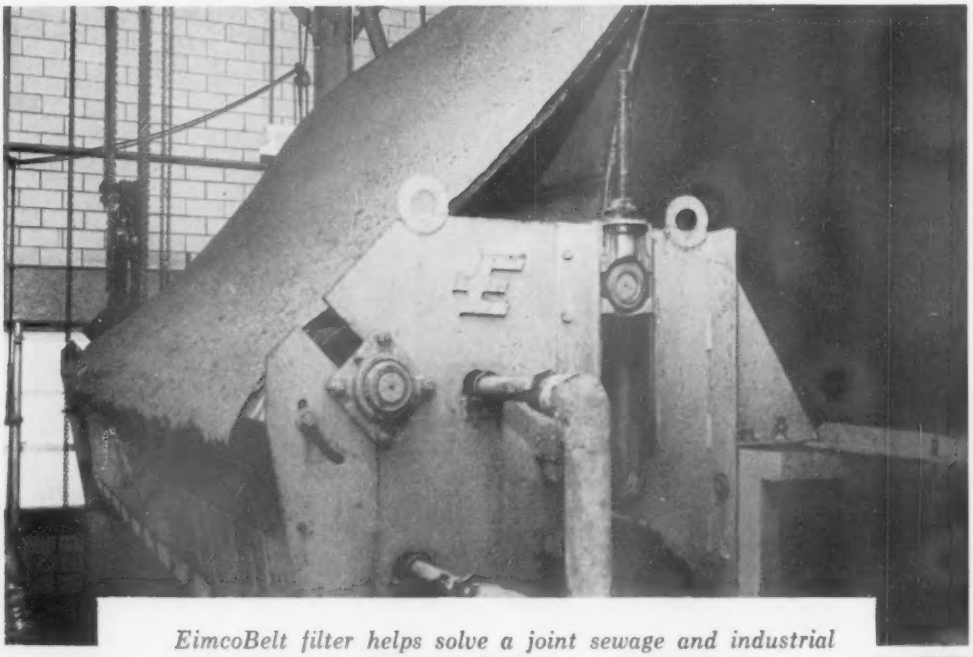
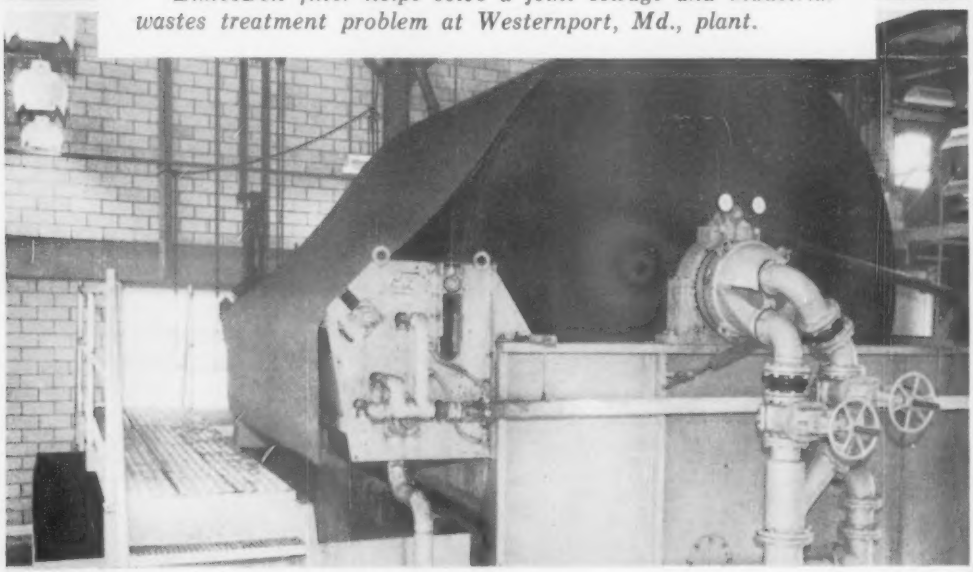


EimcoBelt filter helps solve a joint sewage and industrial wastes treatment problem at Westernport, Md., plant.



EIMCOBELT filter at Upper Potomac

How municipalities and industry can work together to advantage to curb stream pollution is demonstrated by the new treatment facilities of the Upper Potomac River Commission at Westernport, Md.

The plant handles waste effluent from the West Virginia Pulp and Paper Company mill at Luke, Md., and will handle domestic sewage from the nearby towns of Westernport and Luke, Md., and Piedmont, W. Va.

Pollution of the North Branch of the Potomac River has been materially reduced . . . and through this unusual municipal-industrial-governmental co-operation, the three municipalities get low-cost sewage disposal.

Important, in keeping treatment costs low at Westernport is the 11½-ft diameter by 12-ft EimcoBelt continuous belt filter used for dewatering the combined raw primary and waste activated sludge.

The EimcoBelt filter handles sludge feed rates of 400 gpm and produces up to 1½-in. cake at rates of 10 to 15 dry lb/hr/sq ft. Chemical conditioning is not required for dewatering this difficult sludge.

Ask the Eimco representative in your area to help you and your consultants estimate savings in your plant with EimcoBelt continuous belt filters. Write Eimco Filter Division for Bulletin FJ-2053.

Consultants for Upper Potomac River Commission plant were Hazen and Sawyer and Gibbs and Hill, New York, N.Y.

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SEE — EIMCOBELT Filter at WPCF Convention!

Eimco and Eimco-Process sanitation equipment specialists will be available in the Eimco booth — men who have helped hundreds of sewage treatment engineers and operators get lower treatment costs.

Bring your questions to Milwaukee
October 8 - 12

BLESSINGS OF DIVERSIFICATION

In the past year the pace of sales and application of the Coilfilter, especially on Fresh Solids Dewatering, has continued to hold up remarkably well when we realize that while the disposal of sludges continues to be a vexing problem, other matters in the Sanitary Field have become more pressing.

On a nation-wide basis it is apparent that better effluents are required to keep pollution under control and we are hearing the word "tertiary" treatment used more frequently. We are also watching the gradual evolution of Federal participation in pollution control aid in the drainage basins.

Our research and development people have been cognizant of these ever growing needs and we are pleased to note that the line of equipment we manufacture is well suited for the needs of the Sanitary Field. The range includes such items as the homely ejector at one end and advanced electronic devices at the other extreme.

All items of equipment we manufacture are built to meet the needs of the Operator and are conservative in design. Our good reputation was built on this philosophy and we are indeed happy with the eminent position gained.

Respectfully,

T. R. Komline

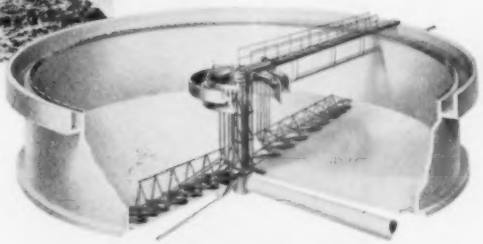
KOMLINE-SANDERSON
ENGINEERING CORPORATION
PEAPACK, NEW JERSEY, U. S. A.
BRAMPTON, ONTARIO, CANADA

Here's a DORR-OLIVER PROCESS TEAM

for efficient

ACTIVATED SLUDGE PLANT OPERATION

The Dorr-Oliver® INKA AERATION SYSTEM



The DORR® RSR CLARIFIER

Key requirements for efficient utilization of the activated sludge process are an effective aeration system and continuous, controlled removal of sludge from secondary clarifiers. You get both in the combination of the new Dorr-Oliver INKA Aeration System and the Dorr RSR Clarifier.

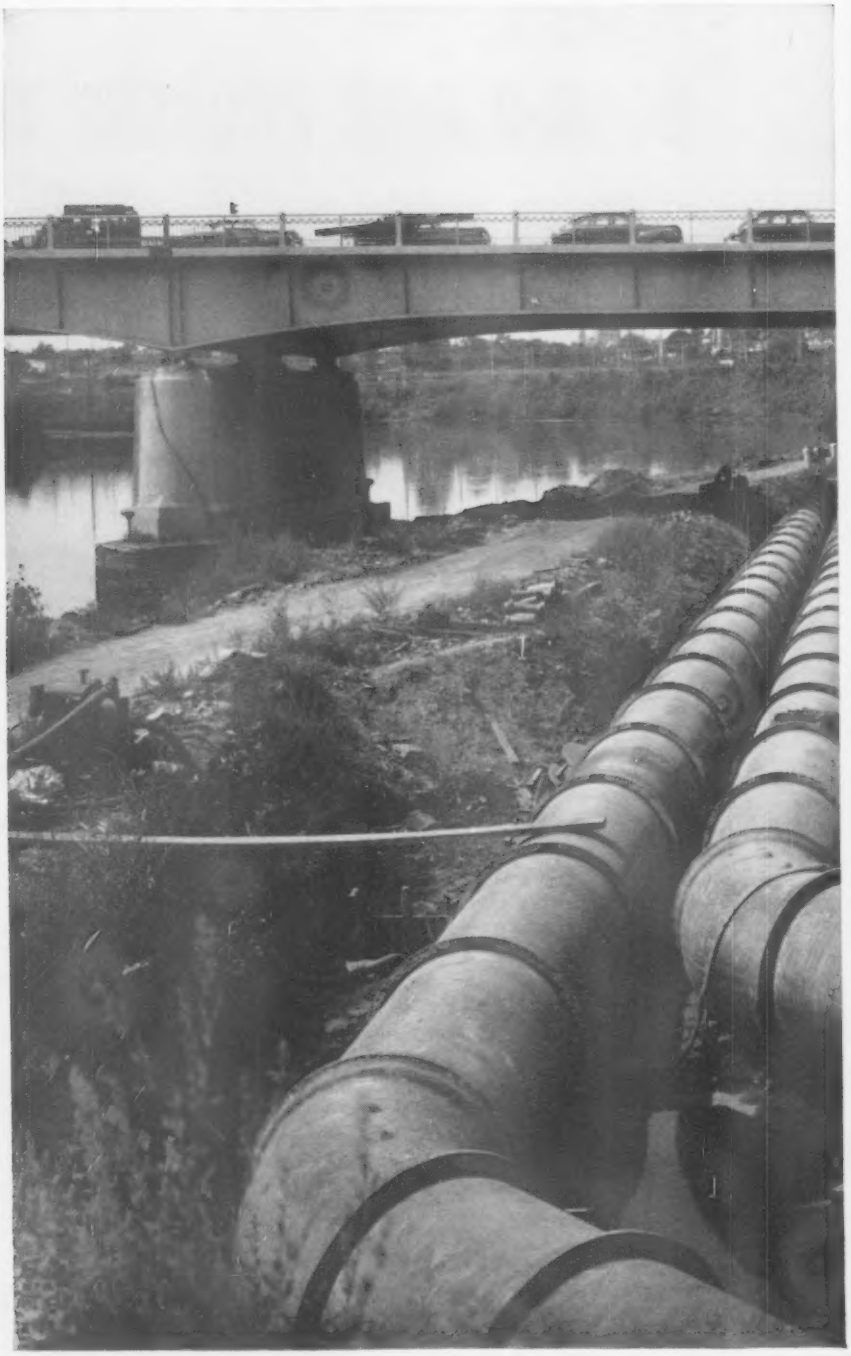
The D-O INKA System offers an entirely new approach to activated sludge aeration. Large volumes of low pressure air, supplied by low cost ventilating-type fans, provide for optimum mixing conditions and high oxygen absorption. Operating costs are exceptionally low.

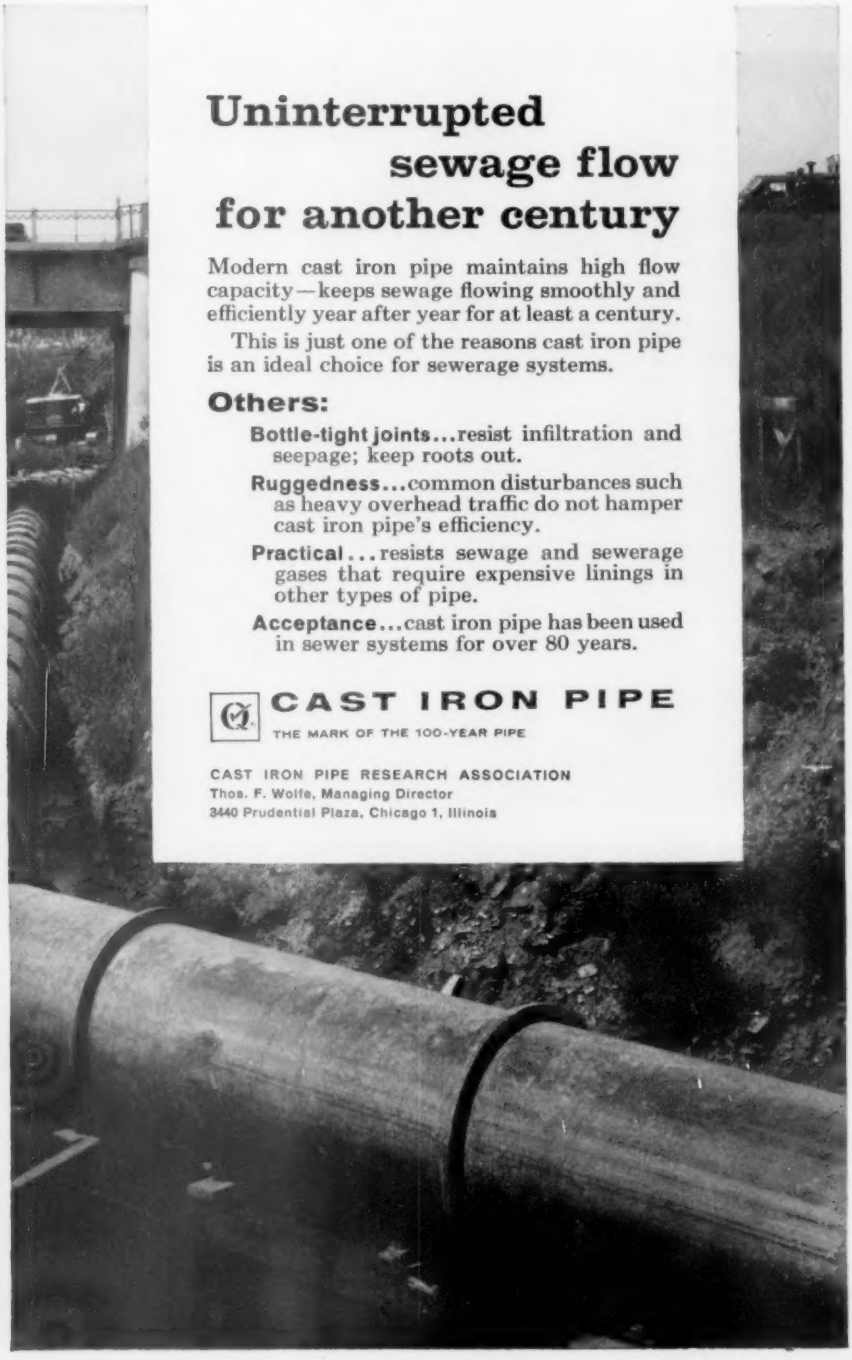
With the Dorr RSR Clarifier, sludge removal is rapidly and continuously handled by rotating uptake pipes. Quality and quantity of sludge removed can be visually observed and easily controlled. Problems of excessive sludge detention in the final clarifier are eliminated, due to the rapid and complete removal of the biologically active sludge.

Together, the D-O INKA System and the RSR Clarifier offer an economical, highly efficient processing team. For more information, write Dorr-Oliver Incorporated, Stamford, Connecticut.

DORR-OLIVER

WORLD-WIDE RESEARCH • ENGINEERING • EQUIPMENT





Uninterrupted sewage flow for another century

Modern cast iron pipe maintains high flow capacity—keeps sewage flowing smoothly and efficiently year after year for at least a century.

This is just one of the reasons cast iron pipe is an ideal choice for sewerage systems.

Others:

Bottle-tight joints...resist infiltration and seepage; keep roots out.

Ruggedness...common disturbances such as heavy overhead traffic do not hamper cast iron pipe's efficiency.

Practical...resists sewage and sewerage gases that require expensive linings in other types of pipe.

Acceptance...cast iron pipe has been used in sewer systems for over 80 years.

CAST IRON PIPE

THE MARK OF THE 100-YEAR PIPE

CAST IRON PIPE RESEARCH ASSOCIATION
Thos. F. Wolfe, Managing Director
3440 Prudential Plaza, Chicago 1, Illinois

clean sewers with

25HP HEAVY DUTY

FLEXIBLE TRUCK-LODER

AND LOAD **5 TO 6 TRUCKS PER DAY!**

PATENT NO. RE 24,908

Sewer to Truck NON-STOP—no complicated auxiliary dumping devices

For the big job, in sewers 24" and up, the Heavy Duty Model Truck-Loder gets the job done FAST by using a 5.4 cu. ft. bucket. Special wide flange rollers to handle the big bucket; heavy duty framing; and the 25 h.p. Wisconsin air cooled engine, make short work of a tough job. Many cities report removing 5 to 6 truck loads of sewer muck in one day.

Like regular Flexible Truck-Loders, the Heavy Duty Model has the streamlined direct truck loading features that other complicated auxiliary devices have never been able to equal. The operator is able to remotely control, shake and thoroughly empty the bucket over the truck. Optional features include the Instant Dual Speed Transmission and a Cable Footage Meter.

Before you buy, check with Flexible – originator and leading manufacturer of truck-loaders. Wide choice of models. Write for details.

FLEXIBLE, INC.

415 South Zangs Blvd., Dallas, Texas
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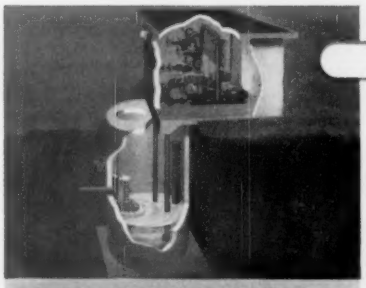
Davco

SPECIALIZED EQUIPMENT

FOR WATER AND SEWER INDUSTRY

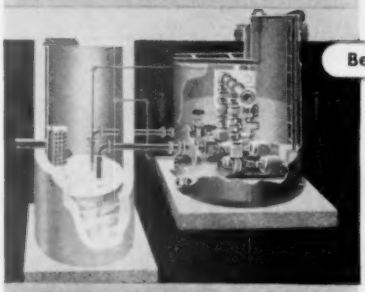


ECONOMICAL

Above Ground Sewage Lift Station

- Lower Purchase and Maintenance cost
- Maintenance Ease
- Most accessible impeller on the market
- Exclusive Davco non-clog self priming sewage pump.

Davco Only Davco offers a complete line of sewage lift stations.

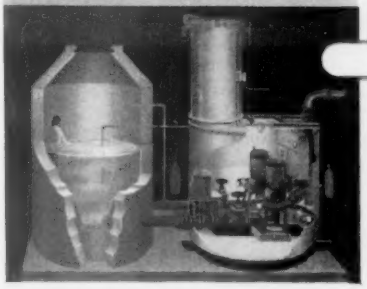


DEPENDABLE

Below Ground Self-Priming Pump Station

- Flexible bulkhead seals or grouted sleeve
- Automatic, time tested controls system.
- Positive high lift self priming pumps.
- Lifelong exterior protection

Davco Davco planning and design service available to consulting engineers.



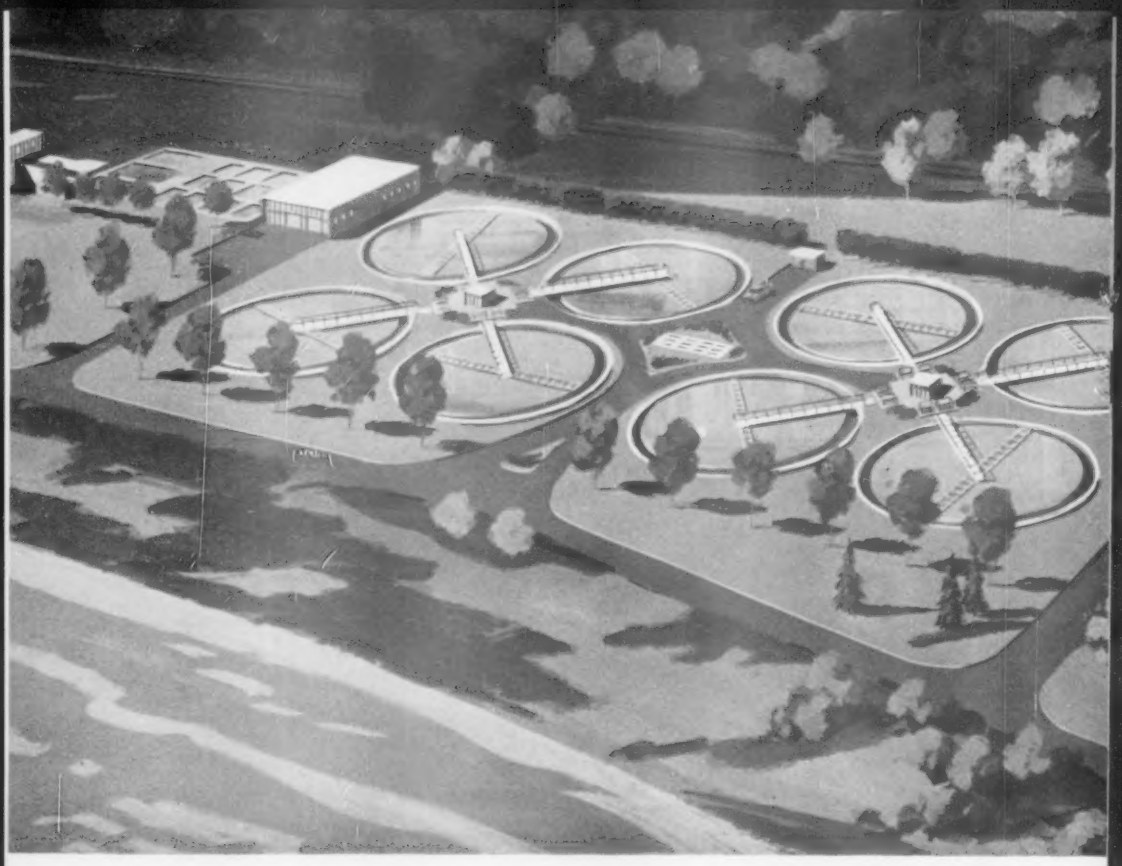
Flooded Suction Sewage Lift Station

- Flexible Bulkhead Seals or grouted sleeve.
- Flood Control Devices
- Automatic, trouble free control system
- Lasting service.

Write today for complete details and specifications

Davco CORPORATION

P. O. BOX 270 THOMASVILLE, GEORGIA CA 6-6458



New $9 million sewage features C-E Raymond Flash

Omaha selects C-E Raymond for second major installation

The City of Omaha recently ordered three C-E Raymond Incinerator Units for installation at its new Missouri River Sewage Treatment Plant now under construction. Henningson, Durham & Richardson are the Consulting Engineers.

This plant will serve an equivalent population of 2,000,000 and will have a dry weather flow of 70 mgd, and an influent capacity of 210 mgd. Treatment will be on a primary digested basis, but the C-E Raymond equipment is designed to incinerate either raw primary or digested primary sludge. The sludge will be burned to a sterile, clinker-free ash, but the plant will be equipped so that the solids from any one of the three C-E Raymond units can be dried for sale as a soil conditioner of low and uniform moisture content. This is the *only* system that permits both drying and incineration—separately or together—in any proportion.

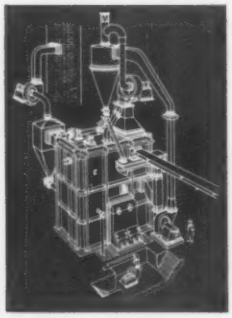
This is the second Omaha plant for which C-E Raymond equipment has been chosen. The first plant, the 12-mgd Papillion Creek treatment plant, for which Henningson, Durham & Richardson were also consultants, has been in operation since 1959. This plant, containing a C-E Raymond Sludge Incinerator System proved the efficiency and economy of this equipment.

Our specialists will be glad to discuss with you or your consultants the many benefits this system can provide your community. For full information contact the C-E office nearest you.

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS;

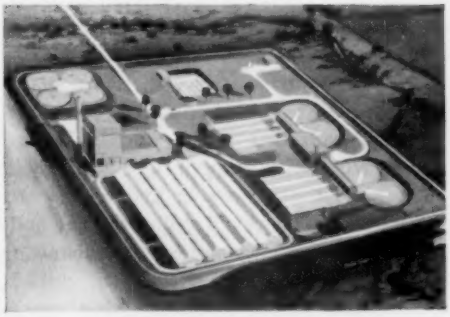
Hawkins-Tolboe-Harlin (a Joint Venture), Omaha, Nebraska, are General Contractors for Omaha's new $9-million Missouri River Sewage Treatment Plant, architects rendering of which is shown above.

treatment plant for Omaha Drying and Incineration System



Right: Omaha's Papillion Creek treatment plant where C-E Raymond sludge disposal equipment has provided controlled drying, efficient incineration and excellent fly ash control since 1959. The Parsons Construction Company was the General Contractor.

Left: The C-E Raymond Flash Drying and Incinerator System provides maximum efficiency in processing filter cake — permits both drying and incineration, simultaneously or separately, in any proportion.



COMBUSTION ENGINEERING

C-329

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New York Offices: 200 Madison Ave., New York 16 • Raymond Division: 427 West Randolph St., Chicago 6, Ill.
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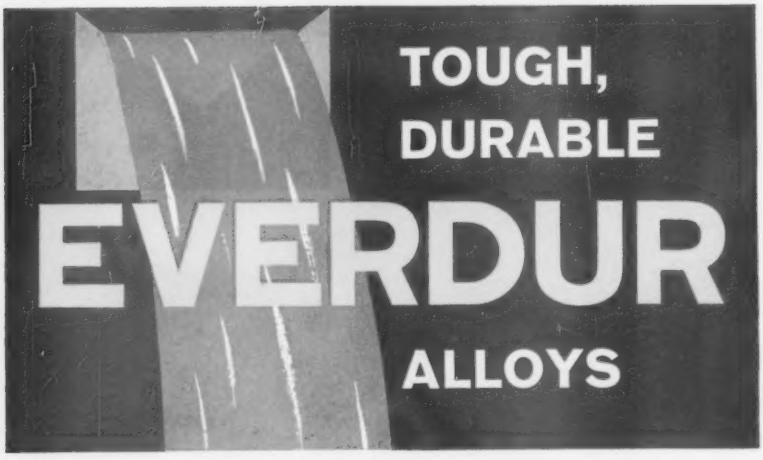
PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE



highly resistant to wear and abrasion in sewage and water works systems

EVERDUR® copper-silicon alloys have excellent resistance to corrosion in all types of water works installations and at all stages of sewage treatment operations. EVERDUR equipment in the United States has been in service *without replacement* for 30 years and longer.

Easily fabricated EVERDUR provides high physical strength with lighter weight. It is used extensively in sewage systems handling corrosive wastes in screens, stems, manhole steps, guides, bolts, weirs, float chambers, troughs. And for water works equipment you will find EVERDUR alloys in long service as surface reservoir outlet screens and screen frames and as large diameter cylindrical well screens in drilled well supply systems. Other uses: spillway fittings, guides, seats and sealing strips. And don't forget EVERDUR Electrical Conduit for use in corrosive atmospheres.

Publication E-11 shows typical applications and other data. Write for your copy—or for assistance from our Metallurgical Dept. in selecting the proper corrosion-resistant alloys for your equipment. Address: Anaconda American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Canada. 61-811

EVERDUR®
a product of
ANACONDA®
AMERICAN BRASS COMPANY

who framed this engineer?

He was Sanitary Engineer working on the construction of an Air Force base in Texas*. He's a good engineer—asked for the right kind of sanitary sewer pipe. But the regulations read "lowest bidder," so he got a substitute that he didn't want.

Six years later the substitute pipeline had to be dug up, at tremendous expense to the taxpayer. Everybody forgot by that time that the framed engineer had screamed for the right pipe in the first place.

Before the war, only Lifetime Vitrified Clay Pipe was used in sanitary sewers on Federal projects. During the war, the Clay Pipe people couldn't keep up with the sudden, unprecedented demand, so standards were lowered to allow substitutes.

There's no Clay Pipe shortage now, and there's still no real substitute for Lifetime Vitrified Clay.

But outmoded Federal, State and Municipal regulations haven't been changed. They can mean many more framed engineers.

And taxpayers are forced to spend millions of dollars each year to replace sewer lines that should have been installed with lifetime pipe—Vitrified Clay Pipe with new cost-cutting factory-made compression joints—in the first place.

Name of Air Force base on request.

NATIONAL CLAY PIPE MANUFACTURERS, INC., *1028 Connecticut Ave. Washington 6, D. C.*

COMPRESSION SEALED, VITRIFIED
CLAY PIPE
IMPERVIOUS
THE STANDARD in SANITARY SEWERS

NATIONAL CLAY PIPE MANUFACTURERS, INC.
1028 Connecticut Ave., Washington, D. C.

Please send me full details on the new factory-made compression joints on Clay Pipe.

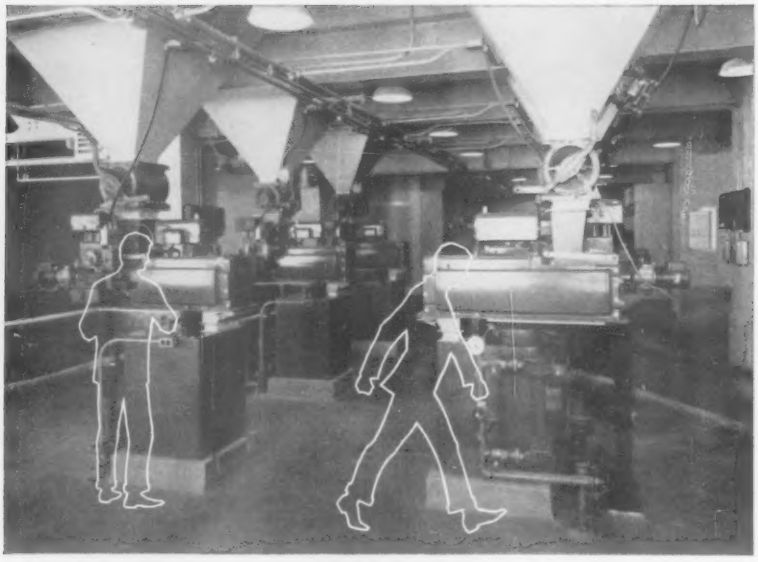
(name)

(company)

(street address)

(city and state)

B-71 WP



SET IT . . . FORGET IT . . .

THE W&T MERCHEN FEEDER

When your dry feeding process calls for accuracy hour after hour, you need Merchen Feeders. Wallace & Tiernan Merchens feed like clockwork without attention . . . never waver in even the most exacting use.

Their 0.1% sensitivity means that a change as small as 1 ounce in a 63-pound belt load automatically corrects the feed gate setting. You get continuous delivery at set feed rate. And you get true gravimetric feeding. Merchens are never affected by density changes. They self-adjust. You select the feed rate; the Merchen does the rest.

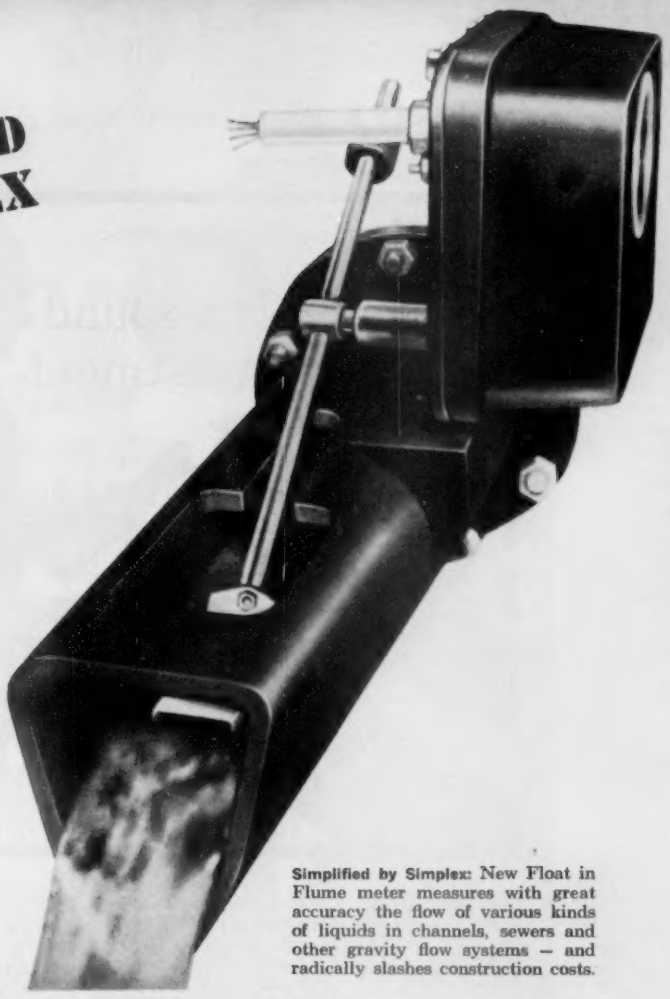
And Merchens give you the other qualities you look for in a feeder: minute-to-minute accuracy within ±1%, rigid, vibration-free construction, compact size to fit almost anywhere.

For more information, write Dept. M-63.84.

WALLACE & TIERNAN INC.

25 MAIN STREET, BELLEVILLE 9, NEW JERSEY

SIMPLIFIED BY SIMPLEX



Simplified by Simplex: New Float in Flume meter measures with great accuracy the flow of various kinds of liquids in channels, sewers and other gravity flow systems — and radically slashes construction costs.

New "Float in Flume" obsoletes the stilling well— saves you its construction cost

Now you can measure open channel or sewer line flow accurately without a stilling well—but at a fraction of the construction, installation and maintenance costs.

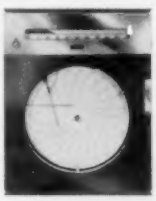
The "Float in Flume" is simplicity itself. A vane, floating atop the liquid passing through the flume, senses the liquid level. This data is transmitted through a Simplex transmitter-receiver system (pneumatic or electric), and is translated into flow terms on a modern, easy to read Simplex type "L" meter.

You save all the costs formerly required by a stilling well: the extra excavation and concrete, float pipe, grating, valves, drain pipe and fittings, cleaning valve and sediment chamber.

You don't even need a purging system. An occasional wiping of the vane is all the cleaning required.

The Float in Flume transmitter may be installed in existing flumes or is furnished assembled with a Simplex Type "S" Parabolic Flume as shown above.

Before you install another meter requiring a stilling well, check the savings of the Float in Flume meter. Drop us a note today and ask for Bulletins 726 and 728.



Simplified by Simplex: New Type "L" Meter is more modern, more compact. Big red-and-white helical indicator replaces pointer, makes reading easier. Continuous type totalizer unsurpassed for accuracy. All parts are mounted on swing-out panel for easy servicing.

SIMPLEX® VALVE AND METER CO.

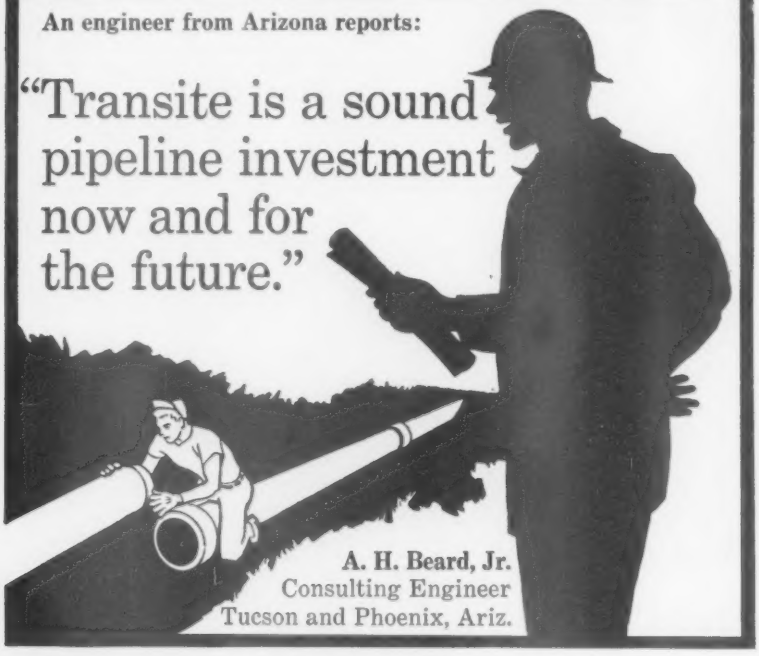
LANCASTER, PENNSYLVANIA

a division of

PFAUDLER PERMUTIT INC.

An engineer from Arizona reports:

"Transite is a sound pipeline investment now and for the future."



A. H. Beard, Jr.
Consulting Engineer
Tucson and Phoenix, Ariz.

"When considering a pipe material for water and sewage projects, 'value' analysis plays an important part in our choice. One of the main questions is whether the pipe will perform reliably now *and* in the future with cost advantages to the client.

"Experience has shown that Johns-Manville Transite® Pipe offers the value we seek. It has proved reliable and at very favorable costs. In addition to savings in handling and installing, Transite's unique Ring-Tite® joints assure that leakage tests will not upset job costs. In numerous tests, Transite lines have regularly been under the 'allowable' specification.

"Installations as old as Transite itself show this pipe outstanding under flexure, crush and hydrostatic conditions. Lengths of Transite excavated here in Arizona for tests showed no signs of internal corrosion after 20 years of dependable service."

For full details, write to Johns-Manville, Box 362, JW-9, N. Y. 16, N. Y. In Canada: Port Credit, Ontario. Cable: Johnmanvil.

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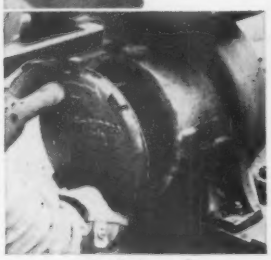
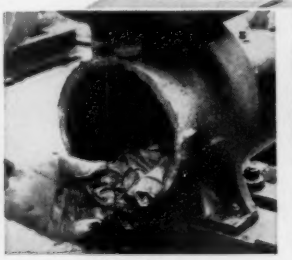
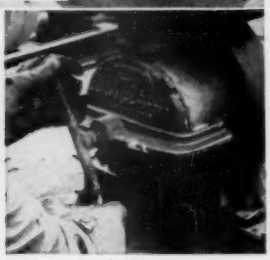
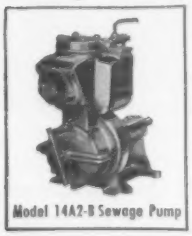
JM


End Plate off


Towel out


End Plate on

"Towels can jam the works, but good!" says Cecil Kent, owner, Sanitation Service Company, Jacksonville, Florida. "I've had 'em clog conventional pumps so bad, it meant a shutdown from two hours to two days.


Model 14A2-B Sewage Pump

"That's why I've standardized on Gorman-Rupp sewage pumps. And what a difference! Fewer shutdowns . . . clogging cleared in just three to fifteen minutes! This cuts average maintenance costs from $120 to only $12 per pump per year. On my 21 Gorman-Rupp pump installations, that adds up to a whopping big saving. Over $2200 a year on parts, packing, materials, and labor.

"Sure, I had a problem—but no more!"

Thrifty, trouble-free, self-priming Gorman-Rupp sewage pumps—2″, 3″, 4″ or 6″ sizes—can be connected to your power or ordered complete with power units. Write for complete specifications.

THE GORMAN-RUPP COMPANY

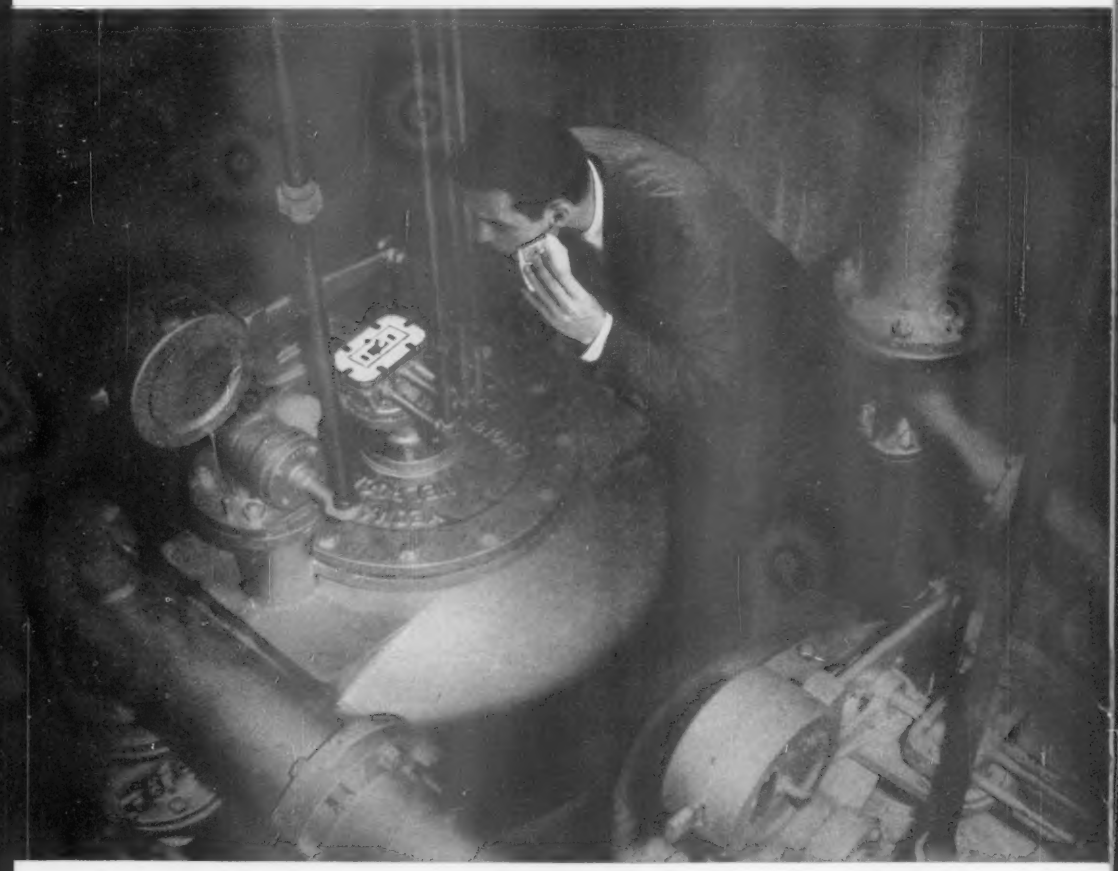
305 Bowman Street **Mansfield, Ohio**

Gorman-Rupp of Canada Ltd., St. Thomas, Ontario

11-2207

See Gorman-Rupp Pumps in Booth 91 — W.P.C.F. Convention

Mirrors, rectangles, and other tremendous trifles make Shone® your bargain buy in sewage ejectors



Would you like to hear more about how these and other design subtleties which make Shone the startling bargain in ***sewage*** *pumping equipment? Call your Yeomans representative. He's in the Yellow Pages.*

When 91 years of engineering and experience go into a **sewage pumping device,** there can be only one result—an ejector that is so much in a class by itself, it becomes an "institution" . . . a piece of equipment that keeps other ways of handling sewage **perennially obsolete** . . . a mechanism that makes embarrassing service interruptions and dangerous climbing in-and-out of manholes things of the past. Each part, each material, each contour, each surface of the Shone ejector has significance in the vital job of handling sewage.

1. Consider the **mirror-like** "superfinish" (you can **actually shave** in it) surfaces of the pilot valve slides and seat of the Shone's exclusive control system. Hand-lapped to perfection . . . only the weight of the valve slide plus pilot air pressure maintain the seal for decades of operation. Faces of the two parts fit so accurately that it is actually difficult to pull them apart. There is no leakage . . . opening and closing are truly positive. Parts do not wear "out of balance," because they are "broken in" before leaving the factory.

2. Piston valve and **pistons** are also "superfinished" to the same mirror-like surface . . . and a test of **each** valve assembly assures operation at only 60% of the **minimum** allowable pilot and operating pressure.

3. Or consider the singularity of **rectangular** valves in round pipes. Sticks and stones in sewage may "bridge" in a round pipe under low-flow conditions. Not only are the Shone's valves rectangular, but they have a larger internal cross section than the pipes to which they are connected. This is one of several reasons why **nothing** (but nothing) can choke a Shone ejector in this "bottleneck" spot. Anything which reaches the receiver passes through it and through the discharge valve.

4. We all know cotter pins are fine on tricycles (and on **external** linkage), but not inside pneumatic ejector inlet and discharge valves. You can't find a more perfect snagger for rags and other strangulating debris. Shone has flush-driven pins on valve hinges, another tremendous trifle.

5. A newly-cast, iron receiver, like any good whiskey, needs to be aged. Receivers for Shone pneumatic ejectors are "mellowed" for up to one year. This settles them down, prevents cracks and warping by relieving internal stresses in the crystal structure. Remember that Shone sewage ejector installations are usually considered permanent — the **first U. S. installation, 1889, is still in service.** An important invisible extra!

6. There are no "missing links" in the control linkage assembly of a Shone ejector. **Each** assembly is set, tested, dowled, and "match-marked" for its **own** particular receiver assembly. No trial and error fitting on the job. Another Shone "intangible" asset.

7. Tipsy control rods are obviously going to be less than 100% efficient. Shone bell rods are sober, straight, and only work with or against the forces of the bells and gravity. There is **no** side thrust to deform the packing seal. A trifle? No, a reason why Shone packing boxes go **years** without repacking.

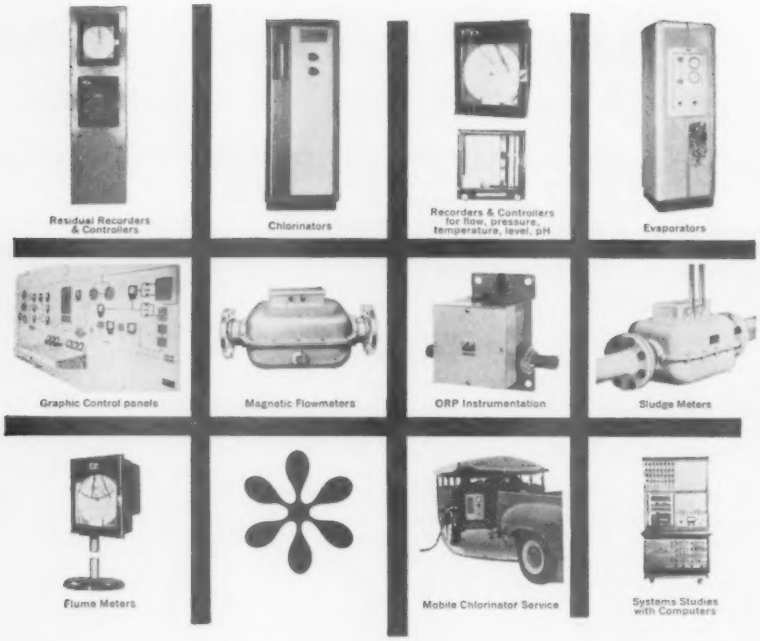
8. Today, nothing is truer than "time is money." A special cast iron header, job tailored for each unit, holds field fitting, pipe cutting, etc., to bare necessities. Duplex units are complete with cross connections. The installer spends his time installing!

YEOMANS

1999-7 North Ruby Street
Melrose Park, Illinois

WASTE HANDLING SPECIALISTS FOR OVER 60 YEARS

E-6142



*For Automation of Waste Treatment . . .

Complete Instrumentation and Chlorination Equipment

Visit us at the convention in Milwaukee BOOTH #104

Why shop around for system components? Save time and money as you design automation for your waste treating plant—and gain years of trouble-free service after installation—with F&P instrumentation and chlorination systems. Flowmeters, recorders, controllers and chemical treatment equipment can all be selected as a coordinated system—from a single, reliable source! And the unusually wide F&P selection means we can recommend without prejudice.

For basic information or specific suggestions, write Fischer & Porter Co., 1191 Fischer Road, Warminster, Pa. In Canada, write Fischer & Porter (Canada) Ltd., 2700 Jane Street, Toronto.

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FISCHER & PORTER COMPANY

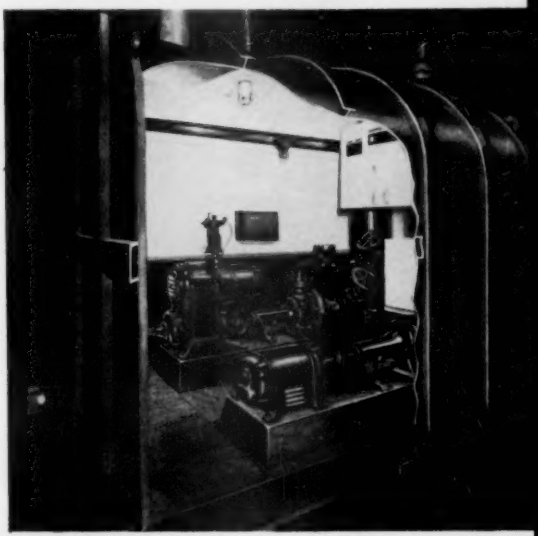
CHLORINATION AND INSTRUMENTATION

FROM TEX-VIT

New Equipment Development

The Revolutionary Rectangular-Shaped Packaged Pump Station

TEX PACKAGED QUAD PUMP STATION



TEX-QUAD is designed to fit the equipment!

For years manufacturers have been forcing bulky sewage pumping equipment into round or oval stations when the equipment is designed for a rectangular station.

TEX-QUAD is designed for the operator!

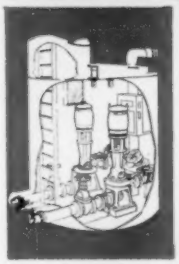
The servicing of a pump or motor is frequently a two-man job. In "old style" stations, this function is hindered. With the TEX-QUAD operators are given every consideration!

TEX-QUAD "Level-Line" pumps increase serviceability!

Its rectangular design permits the use of horizontal pumps which eliminates the suction elbow found on vertical pumps. This improves the hydraulic flow in the suction inlet of the pump.

TEX-QUAD can provide more room for future additional pumps!

Its new shape allows for the addition of pumps and motors as needed. Depending on the size station, as many as five pumps can be used to handle a total capacity up to 10,000 GPM!



ROUND PUMP STATIONS, TOO!

TEX-VIT's Round Pump Station gives you extra rugged design, construction and dependability, too. Its four-bearing pump assembly with Flexible Coupling is housed in a heavy steel, water tight shell.

This station's exclusive features assure maximum dependability and simplify future modification.

Greater Reliability With Other TEX-VIT Equipment Designs

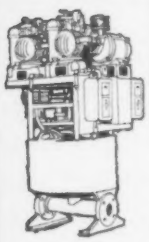
ELLIPTO-JECT or DELTA-JECT

Packaged Pneumatic Sewage Lift Stations

Both packaged stations perform the same function. But the ELLIPTO-JECT is a simplex pneumatic ejector station, and the DELTA-JECT is a duplex station.

Their heavy steel shell-within-a-shell design provides maximum protection for the air storage tank, sewage receiver, controls and other components.

Available in 20 to 200 GPM capacities, both stations will handle large solids and operate odor-free (because they are hermetically sealed). They feature a wide degree of flexibility and are easy and economical to maintain. Each performs without troublesome bar screens, grinders or moving parts in the sewage.



EJECT-ALL

Pneumatic Sewage Ejector

This simple, highly-effective mechanism lifts sewage by means of compressed air. It eliminates many disadvantages inherent in centrifugal pumps.

Because there are no moving parts in contact with sewage, maintenance is held to a minimum. Without the use of bar screens, the EJECT-ALL will handle any solid that can pass through the house service line. It is available in 20 to 600 GPM capacities.

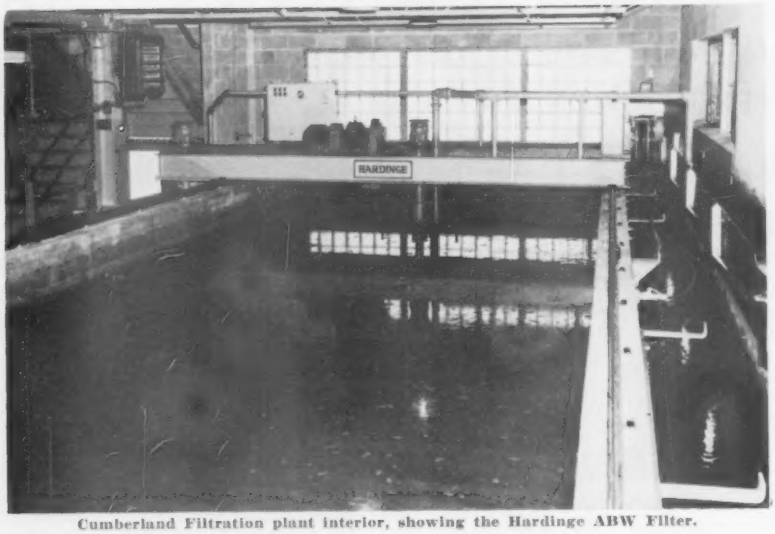
Write today for catalogs on any products by . . .

TEX-VIT

MANUFACTURING COMPANY

Formerly TEX-VIT Supply Company

P. O. BOX 117-J MINERAL WELLS, TEXAS



Cumberland Filtration plant interior, showing the Hardinge ABW Filter.

ABW SAND FILTER PROTECTS MUNICIPAL WATER

In the attractive New England village of Cumberland Hill, Rhode Island, is located a municipal water treatment plant which, since 1955, has been serving the Town of Cumberland urban district in north Rhode Island.

Water from Sneech Pond receives chemical treatment and flows through flocculation and sedimentation chambers where most of the flocculated solids settle by gravity.

The water next flows to Hardinge Automatic Backwash Sand Filter, in which the remaining traces of suspended solids are removed, producing a sparkling water.

Handling 60,000 gallons per hour of water, the Hardinge Filter bed measures 12½′ wide x 42′ long, with a compartmented sand bed 11″ deep, supported on porous plates. The novel feature of the filter is its traveling backwash carriage, which automatically travels the length of the filter bed, to backwash and clean one compartment of the filter bed at a time while the balance of the filter continues to operate in a normal manner.

Water is processed continuously without shutdown of the filter for backwashing. The filter bed is kept essentially free of sediment, since the latter is removed frequently as it accumulates. Head pressures, therefore, remain low and constant.

These filters, complete with all controls, are available in unit sizes from 500,000 G.P.D. to 5,000,000 G.P.D. Multiple units can provide unlimited capacities.

HARDINGE
COMPANY, INCORPORATED
Main Office and Works • 240 Arch St., York, Pa.
"Hardinge Equipment—Built Better to Last Longer."
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TORONTO
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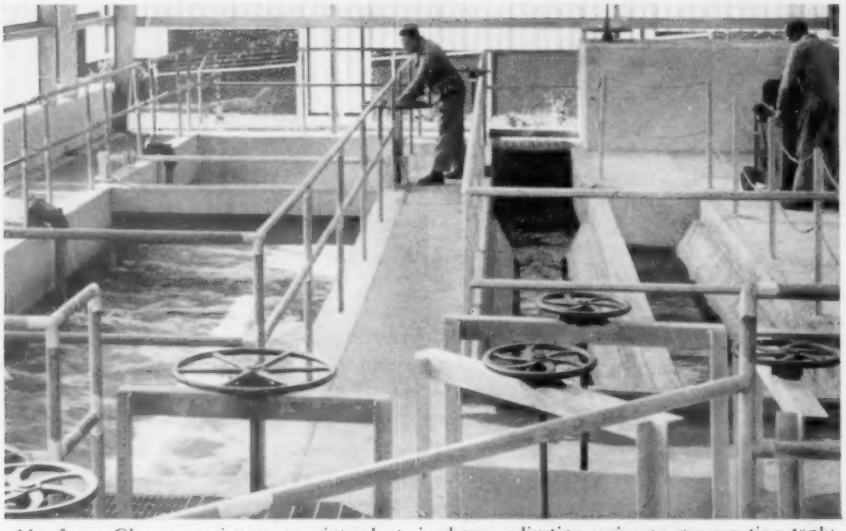
BIRMINGHAM

Southwest Suburban Sewage Treatment Plant, Seattle, Washington

"Four years of excellent protection with Rigortex® Enamel"



Mr. Jerry Gleaves, assistant superintendent, is shown adjusting weirs on pre-aeration tank; while Mr. Otto Dethlefs, maintenance foreman, moves sludge grinder into position.

This ¾-million-dollar sewage plant is the most modern in the Pacific Northwest. It was designed by Hill & Ingman, consulting engineers, Seattle, Washington. The problem: to protect the 20'x106'x8' concrete clarifier tanks from the ravages of raw sewage. Added problem: because the tanks stand empty part of the time and the plant is located in a residential area, the paint must be decorative as well as protective.

Inertol Company's solution: Paint the tanks with Rigortex Enamel No. 3324, vinyl, in sea green.

Mr. Ralph Bucklen, superintendent of the 8.25 MGD plant says: "The Rigortex in the clarifier tanks is giving excellent protection after four years of service. I find Rigortex and all the Inertol products I use are durable and easy to clean. They require less painting maintenance and the colors available fit nicely into our plant." Rigortex Enamel No. 3324 is but one of the Rigortex series — highly specialized, tailor-made enamels in attractive colors. Each enamel is designed to meet a particular, bad corrosive and/or abrasive condition.

There is an informative bulletin on Rigortex Enamel—Bulletin S-526, giving specifications and other data. Write for it today.

Inertol makes a complete line of quality coatings for pollution control, water and industrial wastes plants—and swimming pools.

Inertol® **INERTOL CO., INC.**

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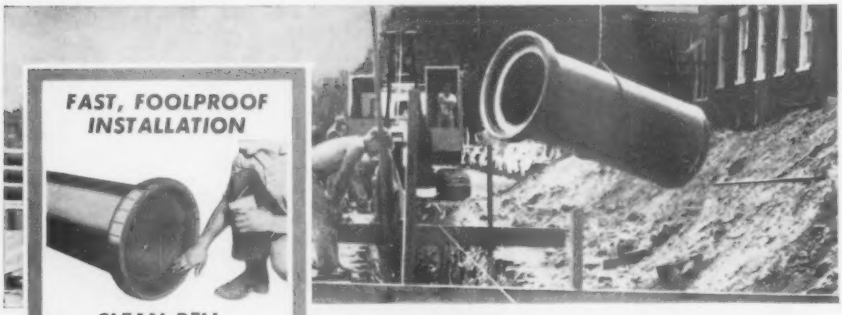
Visit our Booth No. 8, W. P. C. F. Convention, Milwaukee, Oct. 8-12



FAST, FOOLPROOF INSTALLATION

CLEAN BELL

CLEAN SPIGOT

PLACE RUBBER "O" RING IN SPIGOT GROOVE

LINE UP, SHOVE INTO PLACE THAT'S ALL THERE IS TO IT!

TODAY'S

FAST, TIGHT, TOUGH FACTORY-MADE JOINT

Wedge-Lock* Type "O"

BY ROBINSON

Now Available In Diameters Through 36"

Now, lines go in faster, seal tighter, stay trouble-free longer. Robinson Type "O" joints reduce laying time . . . cut installation costs . . . are ideally suited to difficult installation conditions. New precision-tight Factory-Made Wedge-Lock Type "O" joints handle infiltration and roots in any terrain.

THE ROBINSON CLAY PRODUCT CO.
ESTABLISHED 1856
AKRON 9, OHIO

*Patented. T.M. Reg. U.S. Pat. Off.

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You get quick delivery of all sizes from strategically located Robinson branches.

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on Robinson Factory-Jointed Clay Pipe, Call the Robinson Branch Office nearest you.

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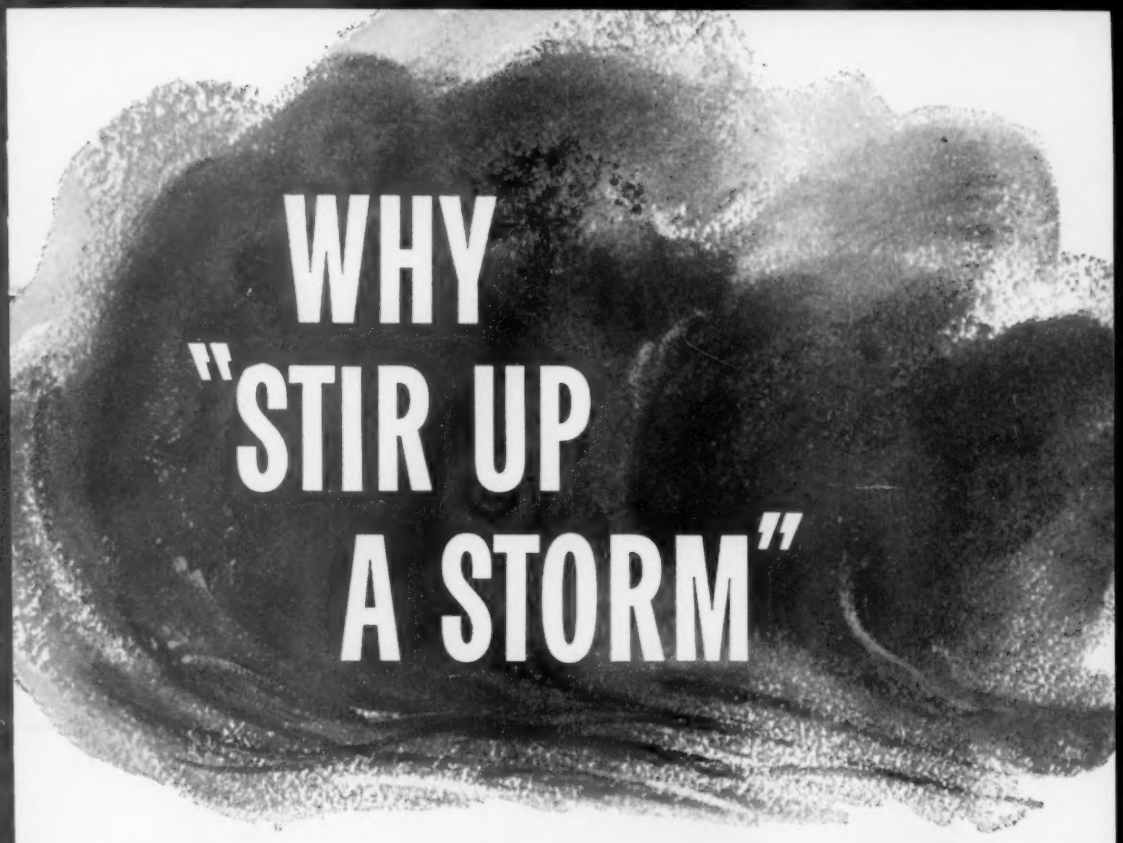


WHY "STIR UP A STORM"

when you want uniform, rapid sludge removal

REX UNITUBE TOW-BRO provides positive, uniform, gentle and rapid sludge removal... with highest possible sludge concentration...*without a storm.*

Because it employs a *gentle suction action only* instead of the conventional plowing or combination plowing and suction action to withdraw sludge, Tow-Bro reduces agitation of the sludge to the absolute minimum. Results: higher solids concentrations... clearer effluent... less volume... most rapid withdrawal rates and maximum possible range of any mechanism. In addition, since sludge is withdrawn at a faster rate ...even with a light sludge blanket... you get greater settling tank capacity and greater operating flexibility. Construction costs are less, too, because no sludge hoppers or center pier is required and tank bottoms are essentially flat.

With Unitube Tow-Bro, a tapered, rectangular header arm revolves slowly around the tank and removes all sludge from the tank bottom in one revolution. Sludge is withdrawn through scientifically spaced and sized orifices in the arm by a gentle suction. Operating costs are reduced since minimum pumping is required to handle sludges of maximum density over the full operating range of withdrawals.

If you're looking for greater capacity... if you're having problems handling activated or trickling filter sludges, or other tricky sludges... investigate Rex Unitube Tow-Bro. For complete facts, send for your copy of Bulletin 315-81. Write CHAIN Belt Company, 4606 W. Greenfield Ave., Milwaukee 1, Wis.

REX®

CHAIN BELT COMPANY

LAYING PIPE UNDER WATER was the tough assignment of Lloyd Kispert & Son, contractors of Green Bay, Wisconsin, at the town of Preble, Wisconsin.

Mr. Lloyd Kispert

ASBESTOS-CEMENT SEWER-PIPE BY KEASBEY & MATTISON

"K&M ASBESTOS-CEMENT GRAVITY SEWER PIPE GAVE US PERMANENTLY TIGHT JOINTS IN WET GOING!"

"This was an extremely rough job. But, with K&M Pipe, we got tight joints in wet going. The K&M FLUID-TITE® Coupling connected easily, even under water. The men just had to lubricate the tapered end of the pipe and slide it into the coupling. We didn't need any heavyweight coupling pullers. Our men had an easy time handling the pipe because of its light weight. We are very satisfied with K&M Pipe and will use it again."

You could lay K&M Asbestos-Cement Sewer Pipe at the bottom of a 58′ deep lake, and it would be infiltration-tight. The smooth bore of this modern pipe remains clean, permanently. The friction coefficient is low. You can plan fewer lift stations and flatter grades.

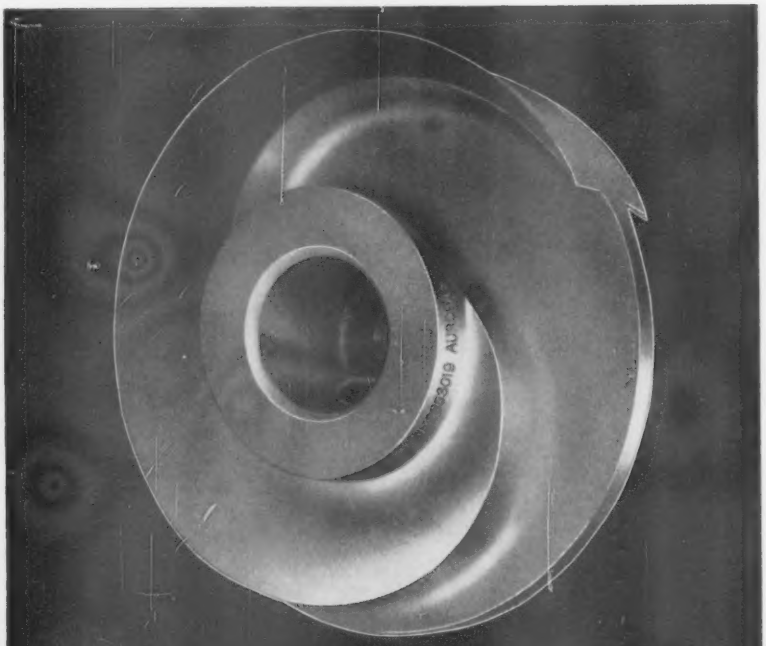
K·M REST IN ASBESTOS

Keasbey & Mattison at Ambler

For more information on this top-quality gravity sewer pipe, write to: Keasbey & Mattison Company, Ambler, Pa., Dept. P-1791.

You can dig flatter grades for K&M Asbestos-Cement Sewer Pipe because its bore remains smooth and clean.

Water, snow, mud, and rain can't hold up the installation of K&M Asbestos-Cement Sewer Pipe.



SINGLE PASSAGE IMPELLERS
WITH MULTI-BLADE BALANCE

AURORA® MONO-VANE NON-CLOG PUMPS

BENEFIT FROM THE SPECIAL ADVANTAGES OF SINGLE PASSAGE IMPELLERS...WITHOUT THE USUAL VIBRATION.

The Mono-Vane patented design provides a natural rotational and mechanical balance. *There is no need for separate counter-balance* . . . and the Mono-Vane can be trimmed to suit various head and capacity requirements, retaining balance through the entire curve from shut-off to wide-open.

The Mono-Vane impeller is especially effective for long, stringy materials . . . and it is up to *20 times more non-clog* than the conventional 2-blade impeller. Maximum economy of investment and operation is assured . . . the Mono-Vane operates effectively for a given head and given solids size at ½ the capacity and *½ the horsepower.*

Ask today for Free Bulletin 1218

AURORA Always PUMPS

AURORA PUMP DIVISION
THE NEW YORK AIR BRAKE COMPANY ®
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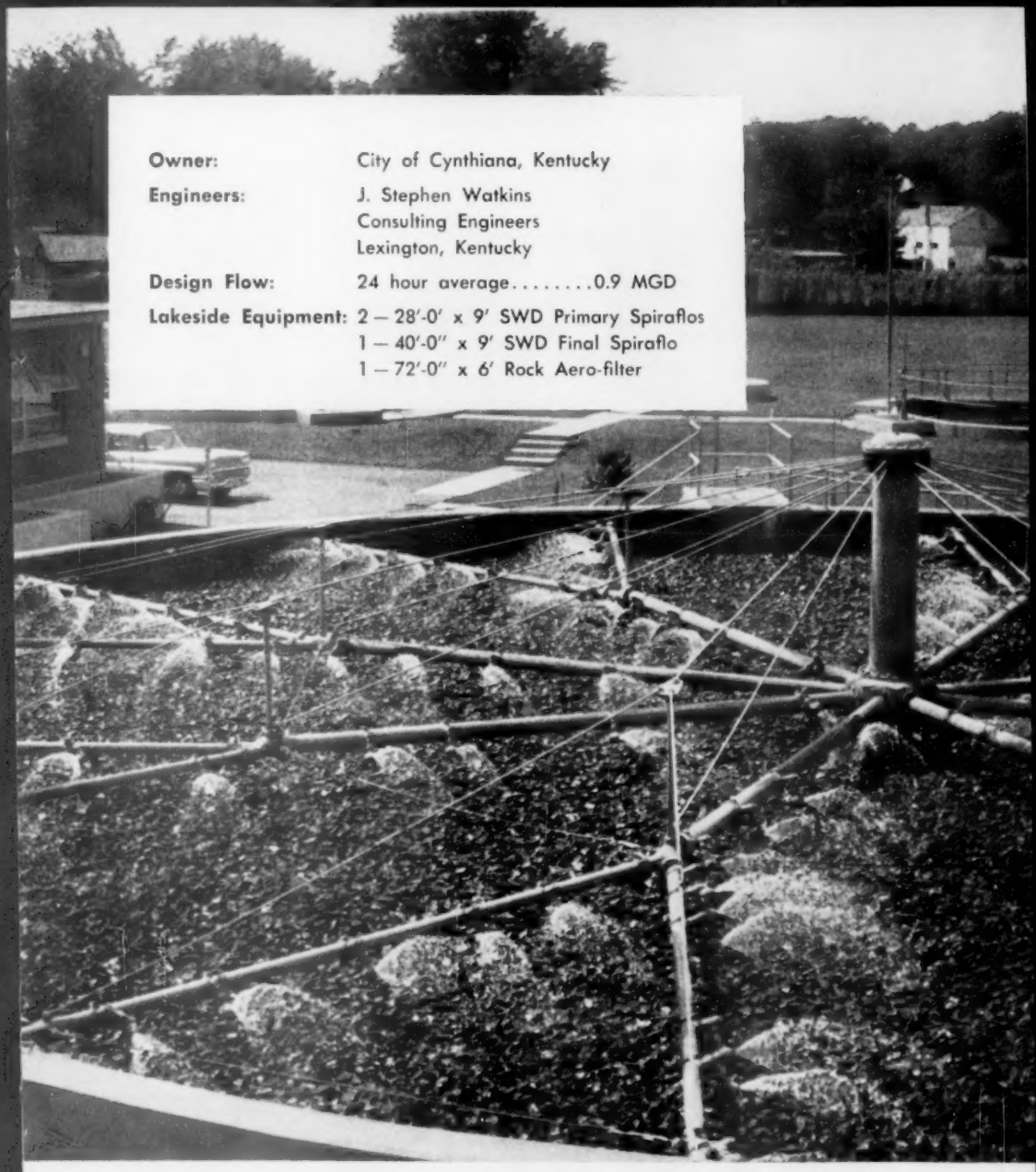


Owner:	City of Cynthiana, Kentucky
Engineers:	J. Stephen Watkins Consulting Engineers Lexington, Kentucky
Design Flow:	24 hour average.....0.9 MGD
Lakeside Equipment:	2 — 28′-0′ x 9′ SWD Primary Spiraflos 1 — 40′-0″ x 9′ SWD Final Spiraflo 1 — 72′-0″ x 6′ Rock Aero-filter

AERO-FILTERS: The high rate filter with raindrop-like application. Proven results based on the biologically accepted facts that proper feeding of a trickling filter will result in a consistently higher BOD removal per cubic yard of filter media. Added advantages include . . . smaller diameter filter beds, less filter fly nuisance, higher hydraulic loadings, and lower recirculation ratios. Over 200 Aero-filters in operation. *Write for Bulletin #116.*

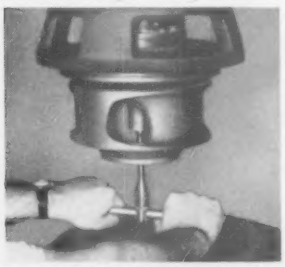
LAKESIDE

ENGINEERING CORPORATION

222 West Adams St., Chicago 6, Illinois

To replace the mechanical seal, the maintenance man throws the circuit breaker to "OFF" and isolates the pump by closing the gate valves. Disconnecting the seal filter lines takes **LESS THAN A MINUTE.**

To connect a hoist between the motor and the ceiling lifting rings, and remove the motor adaptor from the pump volute takes **LESS THAN 3 MINUTES.**



To raise the motor-impeller assembly, remove the impeller locking bolt and release the impeller from the tapered shaft takes **LESS THAN 3 MINUTES.**

S&L

IT TAKES LESS THAN 30 MINUTES

for an average maintenance man to replace the double mechanical seals on a Smith & Loveless "Non-Clog" Sewage Pump under normal conditions, even reading the instructions as he goes along. It doesn't happen very often (some of our seals have been in service over five years) but when it *is* necessary to replace the seal, it's nice to know that it takes him only about 10 minutes to remove the seal housing without special tools (as pictured, step by step) and about twice that long to replace the seal and put the pump back in full service.

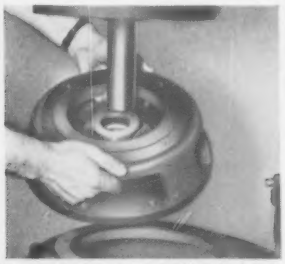
A maintenance man's dream? Yes, because *this* pump was built with him in mind! It's the one pump designed to meet *all* the "must" requirements for sewage service . . . *Write to Department 30*

P.S. And . . . Don't throw away that old seal! Return it to the factory where it can be reconditioned, like new, for a fraction of the cost of a new one.

Smith & Loveless

ONE OF THE UNION TANK CAR COMPANIES

P. O. BOX 8884
KANSAS CITY 15, MISSOURI
PLANT: LENEXA, KANSAS



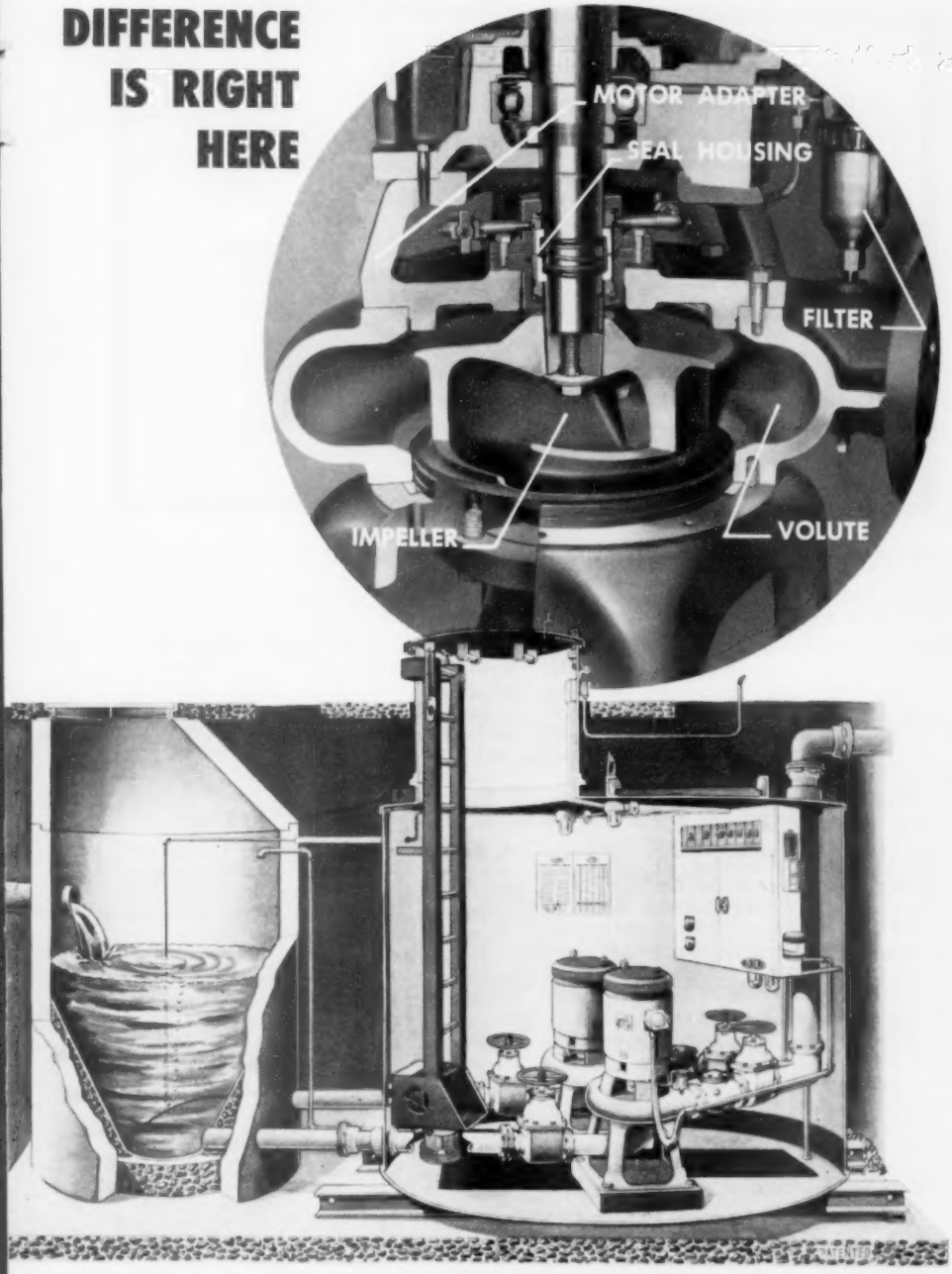
To remove the motor adaptor, that contains the mechanical seal housing, from the motor takes **LESS THAN 2 MINUTES.**

To remove the mechanical seal housing from the adaptor means removing only three alternate screws and takes **LESS THAN A MINUTE.**

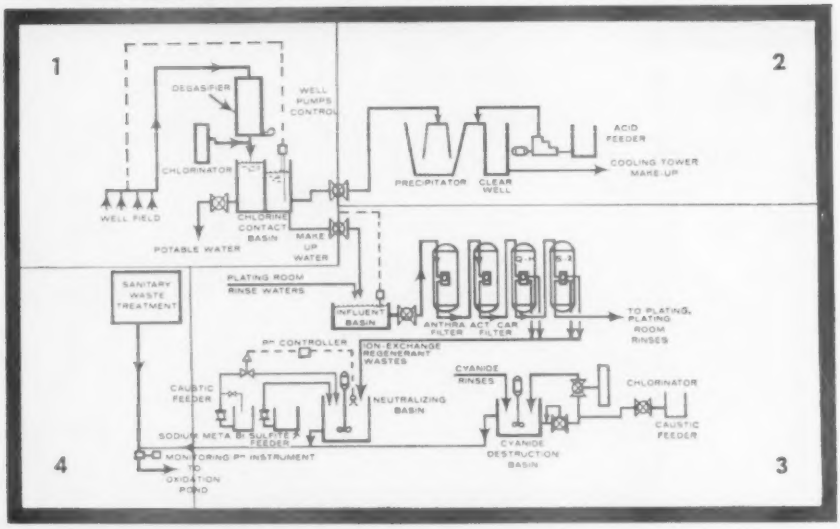
To get to the heart of the mechanical seal and replace the entire unit has taken the maintenance man **ABOUT 10 MINUTES.**

(2852)

THE DIFFERENCE IS RIGHT HERE



FLUIDICS* AT WORK



How many of these water and waste treatment ideas can you use profitably?

From water source to waste disposal this new system now serving the Electro-Mechanical Research Company, Sarasota, Florida, is packed with ideas that can help *you* solve similar problems—and each idea was brought to reality with equipment supplied by Permutit.

1. Well-water treatment (upper left in diagram) handles a minimum flow of 160 gallons per minute from a well field—84 gallons for industrial cooling, 10 gallons for plating rinse make-up, and the balance for potable use. All this raw water is degasified and treated in a Permutit equipment system.

2. Cooling water undergoes further treatment (top right) for reduction of carbonate and bicarbonate alkalinity, by means of a Permutit® Precipitator and acid feeder.

3. Plating room rinse-water demineralizing (center and lower right). A complete Permutit system saves water, saves heat, treats regenerant wastes, and provides high-quality demineralized water for plating rinse. Make-up and plating rinse water is processed through an anthracite filter to remove suspended solids, a Carbo-Dur filter to remove organics, a Permutit Q-H cation exchanger, and a Permutit S-2 anion exchanger. This demineralized water is then ready for use. After plating rinse operations, water is recycled, treated and re-used. Wastes—including cyanide rinses, regenerants, and others—are batch treated.

4. Sanitary waste treatment (lower left) was designed to handle 20,000 gallons per day, treating them first in an Imhoff tank, followed by high-rate bio-filtration, secondary clarification and chlorination.

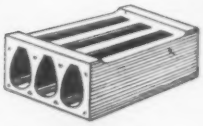
The entire system was engineered by Smally, Wellford and Nalven, Sarasota, Florida. We can cooperate with your engineering consultants to help you obtain similar results. Talk it over with them, or write for our Bulletin 4433, "Water Treatment Equipment," and/or Bulletin 4486, "Equipment for Treating Industrial Wastes."

Permutit Division, Dept. JW-91, 50 West 44th Street, New York 36, New York.

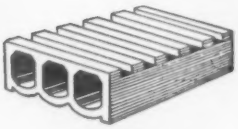
PFAUDLER PERMUTIT INC.
Specialists in FLUIDICS . . . the science of fluid processes

*FLUIDICS is the Pfaudler Permutit program that integrates knowledge, equipment and experience in solving problems involving fluids.

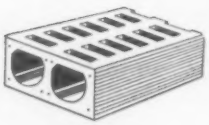
WHY TRICKLING FILTERS SUCCEED for Sewage and Wastes Treatment



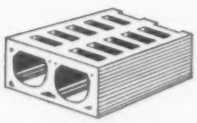
NATCO
Natco Corporation
Pittsburgh 22, Pa.



TRANSLOT
Texas Vitrified Pipe Co.
Mineral Wells, Texas



ARMCRE
Ayer-McCarel Clay Co., Inc.
Brazil, Ind.



BOSCO
Bowerston Shale Co.
Bowerston, Ohio

Nearly 1,000 new trickling filters went into service between 1945 and 1957. The building-pace continues unabated. This is a direct reflection of their economy in construction and efficiency in operation. For many of these filters are working as well today as when first built, even those thirty and more years old. Costly remodeling and rebuilding have been avoided. And no other type is easier to add to if growth exceeds your original estimate.

An important element in this success has been the vitrified clay underdrain blocks in the floors. Clay leads the field in its resistance to corrosive factors such as acids, alkalis and bacteriological action. TFFI Specification clay blocks not only serve right, they are made right—in modern plants under manufacturing controls of quality that substitute materials cannot even approach. Don't be a guinea pig for materials not time-tried and tested. Specify vitrified clay floor blocks and be sure.

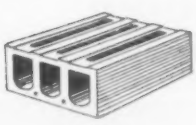
Demand Certified Underdrain Block!

Vitrified Clay Block manufactured by TRICKLING FILTER FLOOR INSTITUTE members and tested by the Materials Testing Laboratory of Rose Polytechnic Institute comply with or exceed ASTM Specification C 159-59T.

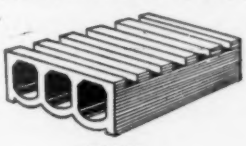
Only TFFI blocks give you a 50-year Guarantee.

TRICKLING FILTER FLOOR INSTITUTE

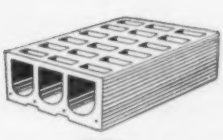
Address nearest member



POMONA
Pomona Terra-Cotta Co.
Pomona, No. Car.



TRANSLOT
Connelton Sewer Pipe Co.
Connelton, Ind.

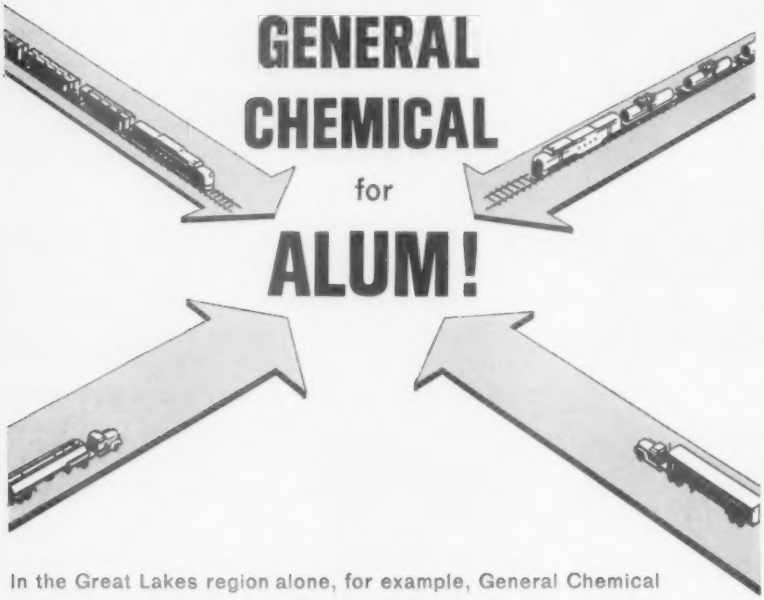


DICKEY
W. S. Dickey Clay Mfg. Co.
Kansas City 6, Mo.

Multiple Sources— Extra Reliability!

...when you call on

GENERAL CHEMICAL for ALUM!



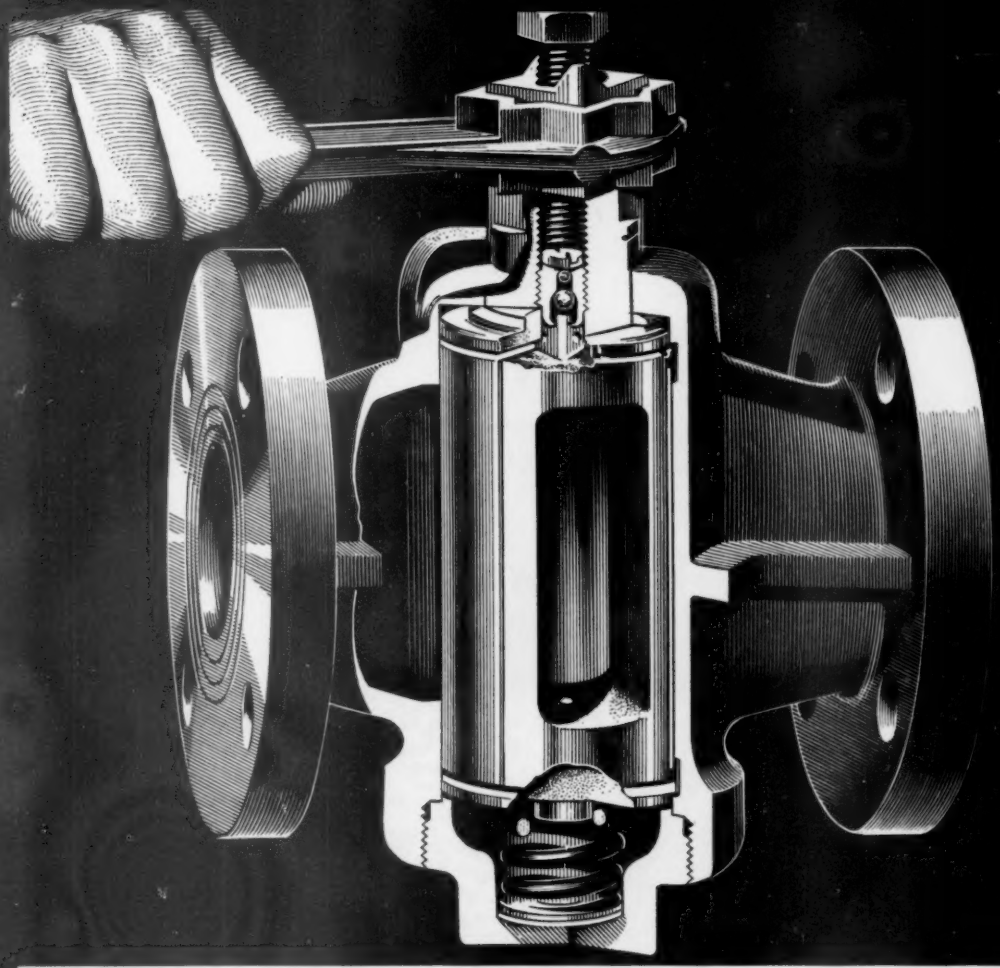
In the Great Lakes region alone, for example, General Chemical has ten plants to serve Alum consumers with speed, efficiency... and certainty. Similar multi-source supply patterns exist in other major consuming areas. Your local General Chemical office will be glad to show you how any of the following alum plants can be put to work for you:

Atlanta, Ga. • Barnet, B. C.* • Chillicothe, O. • Cleveland, O. • Denver, Colo. • Detroit, Mich. • E. St. Louis, Ill. El Segundo, Calif. • Hopewell, Va. • Jacksonville, Fla. • Johnsonburg, Pa. • Kalamazoo, Mich. • Kennewick, Wash. • Macon, Ga. • Marcus Hook, Pa. • Menasha, Wis. • Middletown, O. • Monroe, La. • New Orleans, La. Pine Bluff, Ark. • Port Arthur, Ont.* • Port St. Joe, Fla. • San Francisco (Port Chicago) Calif. • Savannah, Ga. Tacoma, Wash. • Thorold, Ontario* • Vancouver, Wash. • Wisconsin Rapids, Wis. • Valleyfield, Quebec*

Allied Chemical

GENERAL CHEMICAL DIVISION
40 Rector Street, New York 6, N. Y.

*In Canada: Allied Chemical Canada, Ltd.



HOMESTEAD® LUBRICATED PLUG VALVES

performance you can put your hand on

When you take the handle of a Homestead Lubricated Plug Valve, you know that positive low-cost fluid control is at your fingertips. This Homestead Valve is built to very close tolerance, vital to long, effective operation—two thousandths of an inch maximum tolerance on sizes up to 2″ and three to five thousandths on larger sizes. Its *controlled* high pressure lubricant system guarantees complete coverage of sealing surfaces; protection against corrosion; no contamination of line fluids; and no-stick opening or closing thanks to the downward movement of plug during each lubrication. In short, you get performance you can count on with Homestead Lubricated Plug Valves. Get the full story in Reference Book 39-1. Send for your free copy today.

HOMESTEAD VALVE MANUFACTURING COMPANY
"Serving since 1892"
P.O. Box 48, Coraopolis, Pennsylvania

Makers of: Homestead Ball Valves, Cam-Seald, Lever-Seald and Lubricated Plug Valves

"All you're gonna do is
scare the fish cousin Ferd...
you ain't goin' to find
no leaks in them joints"

U.S. cast iron **PIPE** FOR WATER, SEWERAGE AND

not a leak in a lakeful!

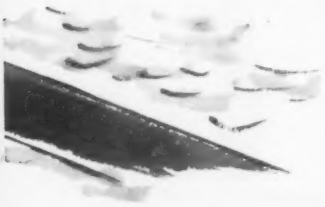
The joints on USIFLEX® Boltless Flexible Joint Pipe are bottle-tight. Joint is made up with a moderate thrust to move ball past self-sealing gasket in socket. Rugged retainer ring locks joint against pull-out during installation and in service. And no wrenches, bolts or nuts to worry about.

Underwater jobs are never easy. But Usiflex simplicity, speed and ease of handling make them almost a pleasure. Want to cut costs, save time and labor next time you have a tough underwater job? Call or write today for illustrated technical brochure on Usiflex.

U. S. PIPE AND FOUNDRY COMPANY
General Office: Birmingham 2, Alabama

A Wholly Integrated Producer from Mines and Blast Furnaces to Finished Pipe.

Makers of TYTON JOINT® Pipe.



USIFLEX
BOLTLESS FLEXIBLE JOINT PIPE

®U. S. Patent No. 2,564,838

1 Insert the gasket in its seat in the socket. Forming gasket loop helps initial stage of seating. Release of loop allows gasket to spring into the gasket seat where it is securely held.

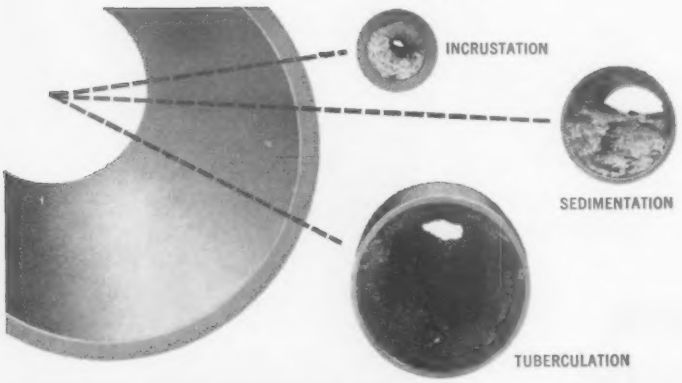
2 Apply special Usiflex lubricant to the ball and inside surface of seated gasket in socket. After lubrication, ball is ready to be pushed into socket.

3 Ball has been socketed. Retainer ring lugs have been lined up with recesses in bell and retainer ring is ready to be moved into the bell and rotated.

4 After insertion and rotation of retainer ring in bell, the lugs on retainer ring are in back of and in register with internal flange segments in bell. Lead lock is partially inserted into recess between the bell and retainer ring.

5 Lead lock completely inserted in recess is being caulked in place by hammer blows on a wide caulking iron.

INDUSTRIAL SEP CAPE ERIE



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National knows how to work quickly reducing supplementary labor costs and service interruptions.

National knows how to clean the difficult jobs, including hard incrustations, unusual obstructions and pipes of unusually large or small diameter.

National knows how to clean long runs with a minimum number of pipe entries.

National knows how to avoid trouble, such as can occur from improper provision for drainage of flush water from large mains or from the use of excessive pressures.

National knows how to clean so thoroughly that restoration of 95% of the original pipe capacity is guaranteed.

National Know-How comes from over 40 years of experience cleaning water mains.

Write or call today for information and prices.

NATIONAL WATER MAIN CLEANING COMPANY
50 Church Street • New York, N.Y.

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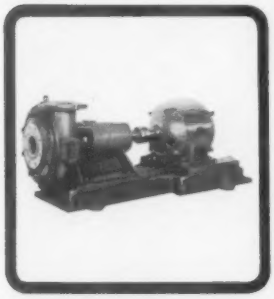
EASTERN SALES REPRESENTATIVE FOR PIPE LININGS, INC.

333 Candler Building, Atlanta 3, Georgia; 920 Grayson St., Berkeley, Calif.; 115 Peterboro St., Boston 15, Mass.; 533 Hollis Road, Charlotte, N. C.; 8 S. Dearborn St., Rm. 808, Chicago 3, Ill.; P. O. Box 385, Decatur, Ga.; 2024 Merced Ave., El Monte, Calif.; 315 N. Crescent St., Flandreau, South Dakota; 3707 Madison Ave., Kansas City, Missouri; 200 Lumber Exchange Bldg., Minneapolis 1, Minn.; 510 Standard Oil Bldg., Omaha 2, Nebraska; 2910 W. Clay Street, Richmond 21, Va.; 502 West 3rd South, Salt Lake City 10, Utah; 204 Slayton St., Signal Mountain, Tenn., 424 S. Yale Avenue, Villa Park, Illinois; 7445 Chester Avenue, Montreal, Canada; 576 Wall Street, Winnipeg, Manitoba, Canada; Apartado de Correos No. 5, Bogota, Colombia; Apartado 561, Caracas, Venezuela; P. O. Box 531, Havana, Cuba; Marquinaria, Apartado 2184, San Juan 10, Puerto Rico; Bolivar 441-A, Marafl., Lima, Peru, Radhusgaten 30, Oslo, Norway

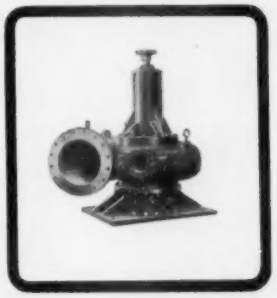
PERFORMANCE-PROVED

Trouble-free years of operation without replacement of major parts, with only routine maintenance, isn't just a claim—C. H. Wheeler pumps are 40 years' performance-proved on the job. (Pumps having higher capacities than those illustrated are available.)

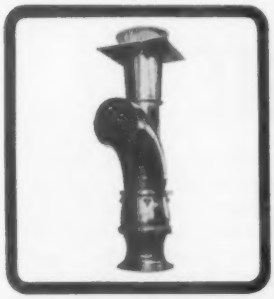


HORIZONTAL NON-CLOG PUMPS. Sewage disposal plants prefer these units for unscreened liquids, sewage. Non-clog impeller, ball bearings, renewable shock absorber. Sizes: 3″—24″. Capacities: 40-5000 gpm. Heads to 160 ft.

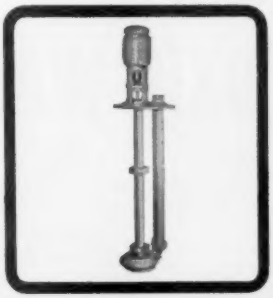
VERTICAL NON-CLOG PUMPS in Open-Shaft and Sentry types for dry pit installations. Many engineering advancements bring higher pump efficiency, lower maintenance costs. Service, performance data and sizes same as Horizontal Non-Clog Pumps.



VOLUTE PUMPS OF MIXED FLOW OR NON-CLOG DESIGN are ideal for many pumping applications including: screened sewage, for drainage, irrigation, flood control and industrial water supply. Horizontal and vertical designs available. Sizes: 12″—48″. Capacities: 3000-100,000 gpm.



AXIAL AND MIXED FLOW PUMPS, in horizontal and vertical designs, for flood control, primary water supply, industrial process work, drainage, etc. High-capacity, low-to-medium heads. Standard or pull-out construction. Sizes: 8″—72″. Capacities: 5000-220,000 gpm and over.



NON-CLOG SUMP PUMPS for heavy-duty drainage, underpass service and sewage disposal. Ideal for industrial and municipal lift stations. These pumps have enclosed, non-clog impellers with wide waterways. Sizes: 3″—14″. Capacities: 20-4000 gpm at heads to 160 ft.

C. H. WHEELER MFG. CO.

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Affiliates:

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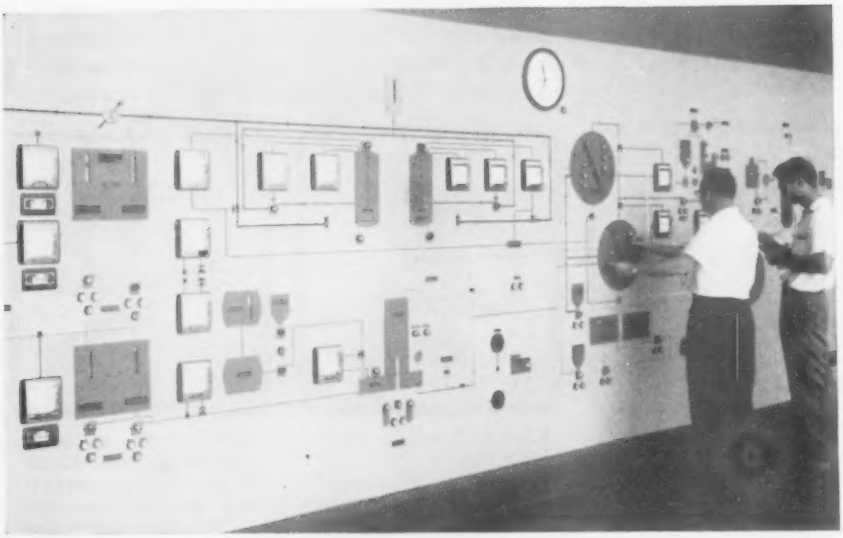
•

KLIPFEL VALVES, INC.

Centrifugal, Axial and Mixed Flow Pumps • Ejectors • Steam Condensers • Marine Auxiliary Machinery • Nuclear Components

THE C. H. WHEELER PUMP TESTING LABORATORY can test pump capacities of up to 150,000 gpm. Accurate scale models of water intake tunnel structures are built and tested in this laboratory. *See your C. H. Wheeler representative or write direct to C. H. Wheeler for help with your problems.*

at **BOEING** Airplane Company...



Central Graphic Control Panel for Boeing's Industrial Waste Treatment Plant. Panel includes controllers for flow and liquid level of various tanks, as well as recorder-controllers for the Foxboro ORP meters. **Consulting Engineers:** *Wilson & Company, Salina, Kansas.*

Foxboro continuous control system

"TAMES" TOXIC WASTE

At the Boeing plant in Wichita, Kansas, toxic hexavalent chromate waste from plating tanks must be reduced to trivalent chromium. Control of this complicated reduction process is handled by a Foxboro Continuous Waste Control System.

Four Foxboro ORP (oxidation-reduction potential) Meters are the heart of the system. These sensitive instruments take continuous ORP electronic measurements — control addition of sulphur dioxide when oxidation potential starts to rise.

Simple or complex — waste treatment systems are everyday business for Foxboro. Years of experience, plus pace-setting instruments like the Foxboro Magnetic Flow Meter, the Foxboro Dynalog* Recorder and the Foxboro ORP Recorder have made it possible.

Write us about your industrial waste treatment problem. We'll be glad to send you literature — or have an engineer call on you at your convenience. **The Foxboro Company, 889 Neponset Ave., Foxboro, Mass.**

*Reg. U. S. Pat. Off.

FOXBORO
REG. U.S. PAT. OFF.
WASTE CONTROL SYSTEMS

6 reasons why...

MARLOW PLUNGER PUMPS HANDLE SLUDGE BETTER!

1 Marlow plunger type pumps are self-priming with suction lifts up to 20 feet and more.

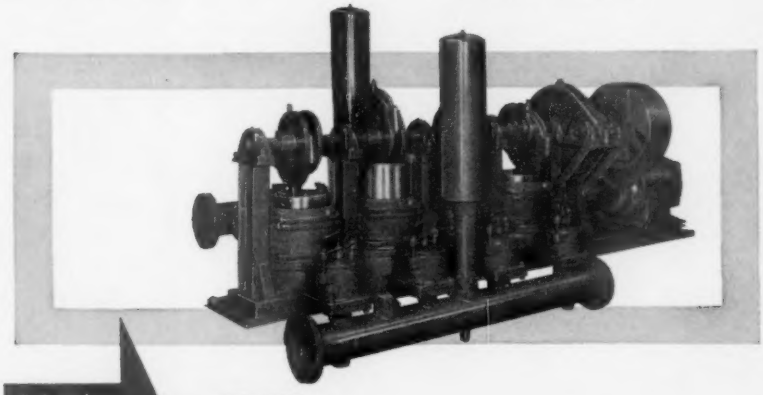
2 Guaranteed quantity for each cycle permits Marlow Plunger Pumps to double as metering unit . . . simplifies operating cycle of treatment plant.

3 Much higher pressures can be developed from Marlow Plunger Pumps than from any other type of pump. They are suitable for applications involving low heads, high pressure or multiple performance requirements.

4 Marlow's variable eccentric permits adjustment of stroke to alter pump capacity, no need for variable speed motors or speed changing devices.

5 Marlow Plunger Pumps can develop higher pressures intermittently, when needed, to clean partially clogged lines. No need for time consuming manual cleaning.

6 Large open areas of pump bodies and ball-valve chambers reduce chances of clogging. Accessible valve chambers reduce down-time of pump should valve assembly clog.



find out how Marlow plunger type pumps can help solve your sludge handling problem. Write for catalog W-59 and complete information.

Marlow PUMPS ®

MARLOW PUMPS

DIVISION OF BELL & GOSSETT COMPANY

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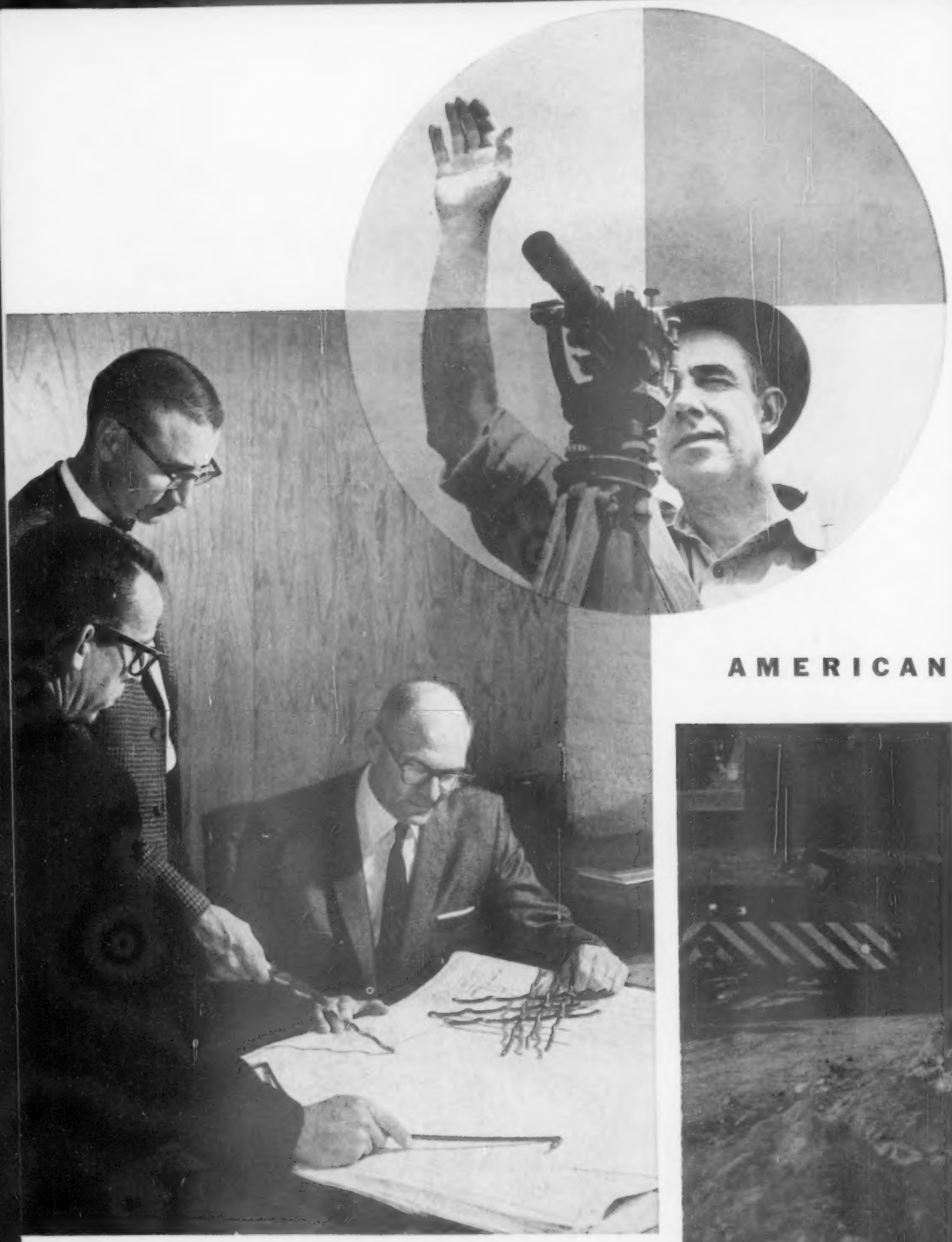
O-568



AMERICAN

First and last it pays to make concrete plans for your community with the best possible medium for water transmission—CONCRETE PRESSURE PIPE.

Your community's future demands concrete planning

Why are so many communities turning to concrete pressure pipe for their main water lifeline of the future? Farsighted waterworks authorities recognize that the present critical demands, brought about by our recent population and industrial explosion, may easily be doubled within the next 25 years.

They also recognize that, with concrete pressure pipe, plans for the future are laid on a solid foundation of an exceptional life span, minimum maintenance requirements and virtually no replacement costs. But most of all, their planning can be accurate, because concrete pressure pipe's initial high carrying capacity will remain unimpaired in years to come when demands on the line will be highest.

WATER FOR GENERATIONS TO COME

Concrete PRESSURE Pipe

CONCRETE PRESSURE PIPE ASSOCIATION

228 North LaSalle Street • Chicago 1, Illinois

TRUE EFFICIENCY WITH FLEXIBILITY

THE TRUE EFFICIENCY of any type of sewage aerating equipment is best measured in terms of oxygen dissolved into the sewage, not air "delivered" to it. Until the oxygen is in solution, it is not available to the aerobic organisms responsible for purification.

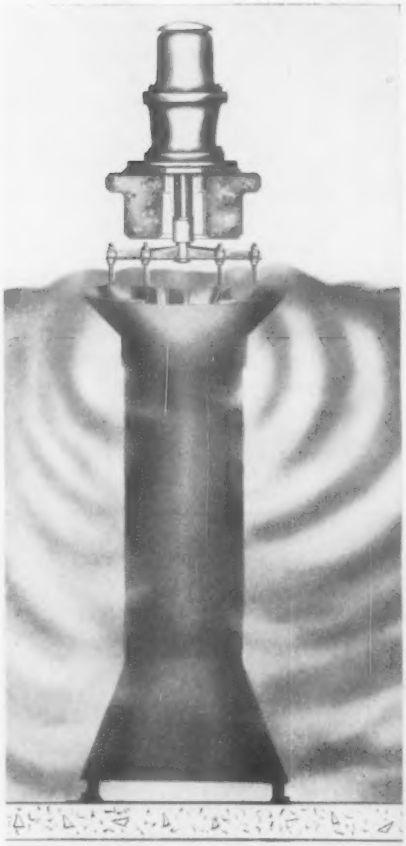
As a result of recent investigations, it is becoming increasingly apparent that oxygen absorption is almost entirely dependent on the rapid and continuous creation of liquid-to-air interfaces. This fact has been long known but not forcibly demonstrated until recently. All oxygen absorption occurs at the liquid "surfaces"—regardless of equipment design or method of aeration.

Therefore, the gauge of efficiency, whatever type of equipment you consider, is "lbs. of oxygen absorbed per KWH."

Compare Hi-Cone's "efficiency rating" with any other aeration equipment. At the same time, investigate the ease with which Hi-Cone handles variations in waste flows and strength through easily adjustable weirs and variable operating speeds. You can get this information by asking your Yeomans representative or the factory for the studies offered at right.

TYPICAL FLEXIBILITY AND EFFICIENCY OF NO. 70 HI-CONE (OXYGENATION CAPACITY—20° TAP WATER)

Inches of Cone Exposure	R.P.M.	Lbs. O_2 Absorbed per Hour at 20° C	NET KW	NET KWH per Lb. Oxygen Absorbed
½	34	37.2	7.0	.188
½	42	57.5	9.9	.172
2	38	38.7	7.3	.189
2	46	54.0	10.0	.185
4	34	27.7	4.9	.177
4	50	54.0	9.5	.176



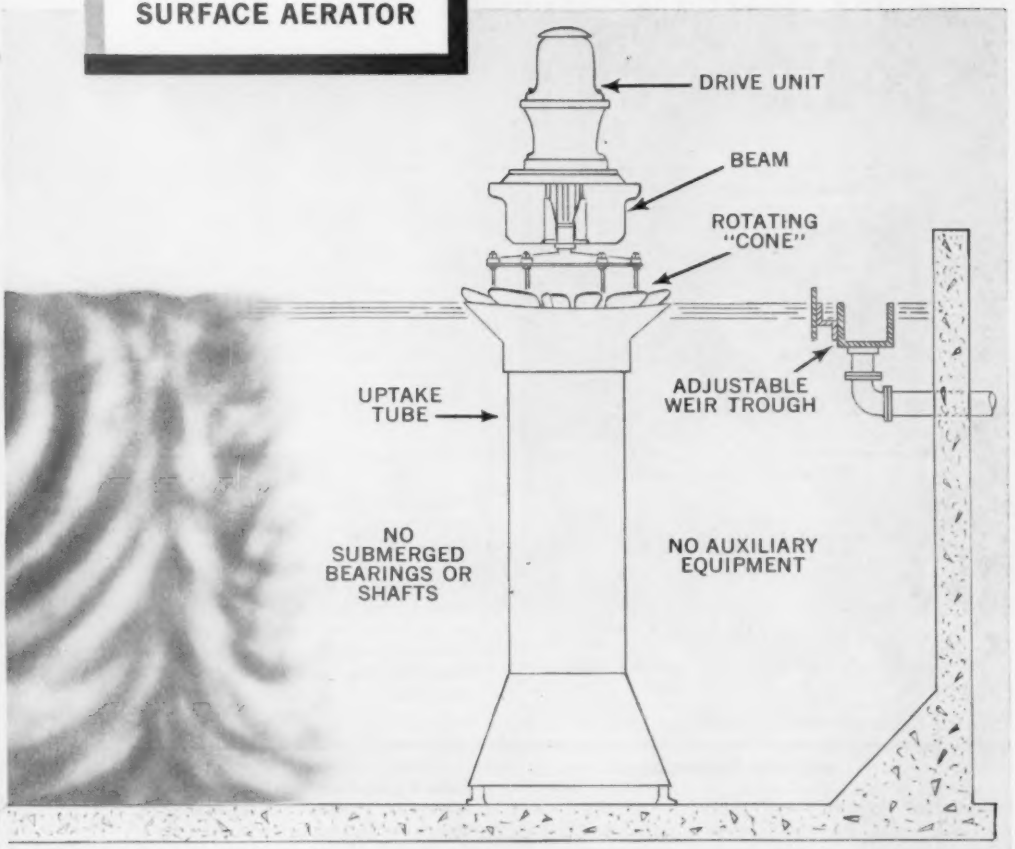
Units for

NOW AVAILABLE!

Basic Data for Evaluating Aeration Equipment

HI-CONE®

SURFACE AERATOR



ALL Sizes of Waste Treatment Plants

- ☐ Activated Sludge Plants
- ☐ Aerobic Digestion Plants
- ☐ Aerator Performance Studies

YEOMANS

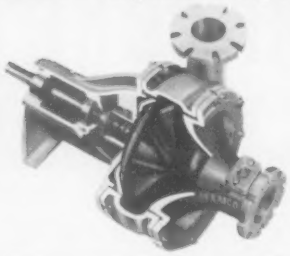
1999-7 N. Ruby Street • Melrose Park, Illinois

WASTE HANDLING SPECIALISTS FOR OVER 60 YEARS

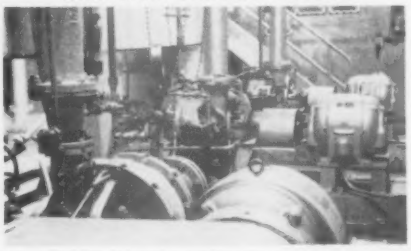
H-6139

WEMCO® The INCREDIBLE Torque-Flow pump!

the pump they couldn't clog

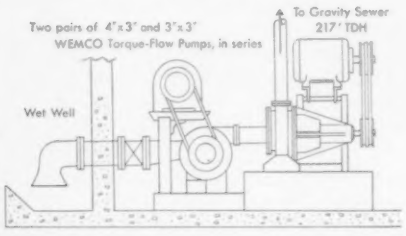


HIGH SAND-CONTENT SLUDGE



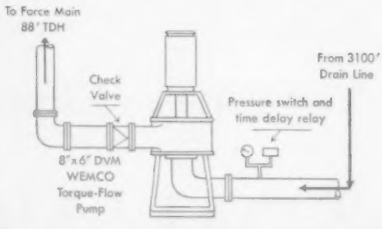
In a new treatment plant enlargement, engineers selected the Wemco Torque-Flow Pump because of sludge containing large amounts of sand, the cause of high maintenance requirements of existing centrifugal pumps. A test installation under varying conditions showed capability to handle the abrasive material without wear, cloggage. This plant now employs eight Torque-Flows for sludge handling and six for digester recirculation.

RAW SEWAGE LIFT



Past, trouble-free experience with Torque-Flow Pumps, led a large southern city to select the Torque-Flow to lift raw sewage from a gravity wet-well to a gravity sewer at 250 gallons per minute against a 217-foot total dynamic head. Results, since installation: no cloggage reported, despite lack of comminuters or bar screens; no maintenance problems from two pairs of pumps installed in series.

WET-WELL ELIMINATED



In Southern California, sanitation engineers, faced with the problem of sewage overflows, designed a lift station, with a Wemco Torque-Flow Pump providing the function of a wet-well. The Pump, rated at 700 GPM at 80' TDH, handles overflow in the line. Exclusive liquid impeller eliminating wear rings and face plates, makes possible no-wear, no-clog operation, without vapor locking, regardless of reduced or intermittent feeds. Maintenance virtually eliminated.

Only Wemco's Torque-Flow Pump with continuous, open passage, liquid impeller could have done it!

Write for more detailed information on Torque-Flow applications today.

WEMCO® *a division of*
Western Machinery Company
650 Fifth Street, San Francisco 7, California

Dowpac provides tremendous surface area in a small volume of space, it weighs little, and tower maintenance costs are negligible.

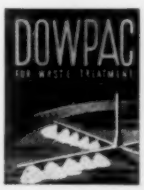
NEW DOWPAC MEDIA TREAT SEWAGE AND WASTE FAST IN LITTLE SPACE

. . . D.I.S. offers low-cost pilot plant to prove system for your waste conditions!

Contoured plastic sheets of Dowpac® packing media interlock (above) to form a continuous, lightweight grid for low-cost treatment of water-borne wastes. Because of light weight and high operating efficiency, a waste treatment system using Dowpac requires much less land area for construction than other waste systems, while operating at higher waste concentrations.

Cost advantages—Economical first cost . . . low maintenance and operating costs . . . conserves expensive land. **Operating advantages**—large area for bacterial growth . . . efficient aeration . . . freedom from plugging. **Total advantages**—a D.I.S. waste treatment system using Dowpac costs you less to install and operate and treats more waste faster, at higher concentrations, than other kinds of systems.

Pilot plants employing Dowpac can be rented or purchased, and D.I.S. engineers will help customers develop the most effective use of Dowpac for their particular waste conditions. Dow Industrial Service works with industries of every kind, anywhere in the U. S. Further, D.I.S. offers consulting laboratory service for water and waste treatment, backed by technical resources of THE DOW CHEMICAL COMPANY. For further information, write or call DOW INDUSTRIAL SERVICE, 20575 Center Ridge Road, Cleveland 16, O., Dept. JWPCF9.



FREE BOOKLET on low-cost, high efficiency waste treatment using Dowpac. Send for a copy today.

DOW

Dowpac is a trademark for packing media—not pilot plants

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WATER POLLUTION CONTROL FEDERATION

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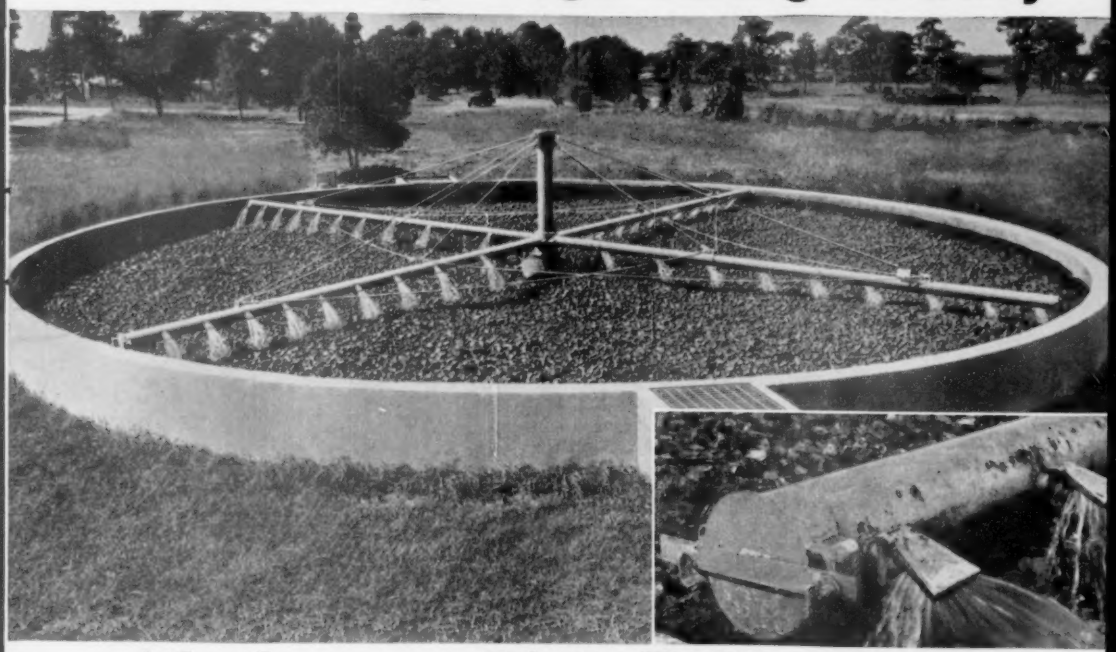
uniform dosing...high filtering efficiency



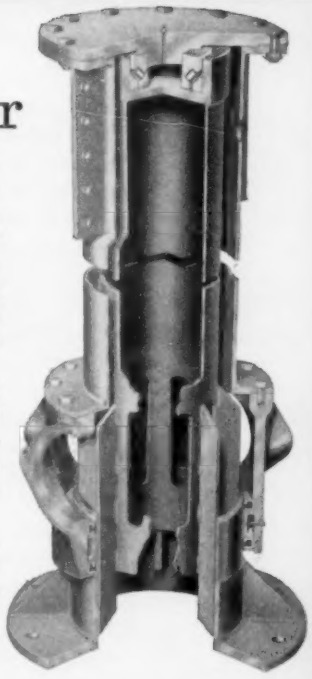
with the new Link-Belt ROTOLINE distributor

Link-Belt's Rotoline distributor—a result of years of experience in designing and manufacturing a complete line of equipment for treating water, sewage and industrial waste—offers an efficient, low-cost means of dosing the filter bed.

The Rotoline distributor is made to operate on trickling filters from 20 to 200 feet in diameter. Wide angle spray nozzles provide large area coverage and positive and uniform distribution over the entire filter surface. Large nozzle area design provides access for easy cleaning and minimum head loss at high flows.

Automatic high flow overflow weir boxes may be provided for two of the arms on a four arm distributor. For low flows, only two of the distributor arms discharge to the filter to maintain sufficient head for rotation. An increase in flow causes the water level to rise until it overflows the weir in the overflow boxes and feeds the other two arms. Thus, rotation at low flows is sure and excessive heads at high flows are prevented.

For complete information, write or call your nearby Link-Belt office. Our engineers will gladly work with your chemists and consultants to provide you with the finest in modern water, sewage or industrial waste treatment equipment. Send for folder 2706.



15,723-A

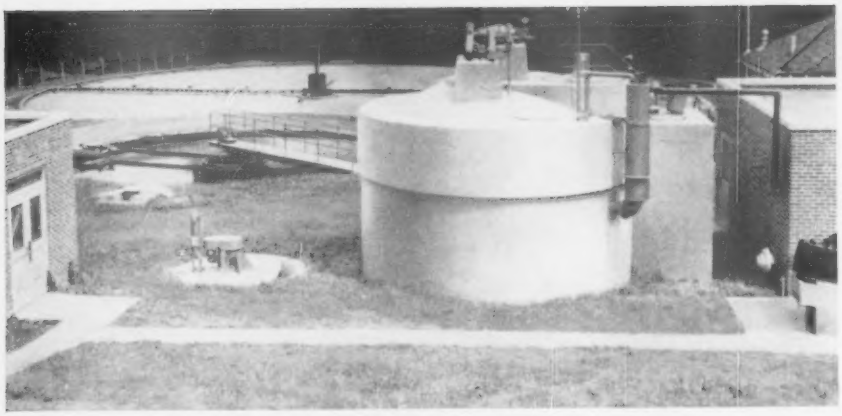
The center column—available in diameters from 6 to 32 inches—is of welded steel and cast iron construction. It can be furnished with either a mercury or mechanical seal. Cutaway shows the mechanical seal between rotating and stationary elements. This efficient seal design assures minimum frictional losses. The top of the center column is provided with an anti-friction bearing and the bottom with a bronze, grease-lubricated steady bearing to support distributor arms.

LINK-BELT

SANITARY ENGINEERING EQUIPMENT

LINK-BELT COMPANY: Executive Offices, Dept. 961-JWPCF, Prudential Plaza, Chicago 1. Sanitary Engineering Regional Offices—Atlanta 10, Chicago 9, Colmar, Pa., Kansas City 8, Mo., San Francisco 24. District Sales Offices in All Principal Cities. Export Office, New York 7; Australia, Marrickville (Sydney); Brazil, Sao Paulo; Canada, Scarboro (Toronto 13); South Africa, Springs; Switzerland, Geneva. Representatives Throughout the World.

See our Exhibit at W.P.C.F. Convention, Milwaukee, Oct. 8-12.



DORRCO VACUATOR SOLVES SEWAGE PLANT MODERNIZATION

at Dixon State School, Ill.

Recent improvements to this 20 year old institutional sewage treatment plant incorporate the principle of vacuum flotation for removal of grease laden waste. This addition augments the action of the old trickling filter, solves the problem of overloading and relieves a previously obnoxious condition in the primary clarifier and the filter bed.

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INDUSTRIAL WASTES CONTROL IN MILWAUKEE

Lawrence A. Ernest

Sewage collection and treatment in the City of Milwaukee and its surrounding suburbs is a function of the Milwaukee Sewerage Commissions. Two Commissions, the five-man Sewerage Commission of the City of Milwaukee and the three-man Metropolitan Sewerage Commission of the County of Milwaukee, provide the intercepting sewers and the Jones Island sewage treatment plant to treat both domestic sewage and industrial wastes originating in the Metropolitan District, formed in 1921 and roughly consisting of the northern two-thirds of Milwaukee County, which is located in the Milwaukee River drainage area (96,200 acres).

The City Commission, created by State statute in 1913, consists of five members appointed for five-year terms by the Mayor and confirmed by the City Council. The Metropolitan Commission, which was formed in 1921 to provide sewer service for the suburban areas, consists of three members appointed for six-year terms. One member is certified by the State Board of Health and one by the City of Milwaukee Sewerage Commission before their appointment by the Governor of the State. The third member is selected and appointed by the Governor. The 1959 State Legislature made possible the expansion of the district within the confines of Milwaukee County on a local option basis. Present indications are that all units of government in the County will join the district except the City of South Milwaukee.

In addition to the areas served in the district, adjoining areas outside the district but within the drainage area have made contracts with the Commissions for the treatment of their wastes. These include the Village of Elm Grove and part of the City of Brookfield. The Commissions are currently negotiating with the Town of Muskego, the City of New Berlin, the City of Menomonee Falls, and the Village of Butler to provide sewer service for the areas under their jurisdiction which lie within the drainage area. These communities would be expected to deliver their wastes to the interceptor system which would be located within the district.

At present the Commissions are engaged in an expansion program, which includes construction of a 60-mgd treatment plant (ultimate capacity, 120 mgd). The expansion program is estimated to cost $52 million and is designed to provide sewage collection and treatment facilities for a portion of the present district, the expected new additions to the district, and adjoining areas in the drainage basin.

The Jones Island treatment plant, placed in operation in 1925, had an initial design capacity of 85 mgd of sewage containing 250 mg/l of suspended solids and 256 mg/l of BOD. It has been increased in size until it now has a capacity of 200 mgd with an average BOD and suspended solids content of 300 mg/l.

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The paper was presented at the 33rd Annual Meeting of the Central States Sewage and Industrial Wastes Assn. in Madison, Wis., June 15–17, 1960.

The plant is a complete treatment plant utilizing the activated sludge process. It cannot, however, be described as a conventional activated sludge plant, inasmuch as fine screens are employed as the method of primary treatment. These screens, with openings $\frac{3}{32}$ in. wide by 2 in. long, screen the sewage after it has passed through conventional coarse screens and grit chambers. All screenings and grits are burned in a multiple-hearth incinerator.

The screened sewage is then mixed with return sludge in the mixing channels and fed into the aeration tanks. Use of fine screens instead of the more conventional primary sedimentation results in the discharge of a strong sewage to the aeration process.

Waste sludge from the circular final clarifiers is conditioned with ferric chloride, filtered on vacuum filters, dried in rotary dryers, and sold as Milorganite, a well-graded organic fertilizer that is sold throughout the country in quantities of about 75,000 tons a year.

Industrial Wastes

Milwaukee, together with several of its suburbs, forms a large industrial complex with an extremely diversified industrial base. In recent years, it has produced goods valued at more than $3 billion annually. Many of the industries contribute large volumes of highly concentrated wastes from the standpoint of BOD and suspended solids. The large brewing, malting, tanning, milk processing, and meatpacking industries contribute the largest proportion of the heavy industrial waste load treated at the sewage treatment plant.

No sewer service charge or surcharge on industrial wastes is levied; therefore, no accurate figure on total industrial waste strength and volume is available. The connected population can be closely estimated, and because daily chemical analyses of composite samples of screened sewage are run, it is possible to estimate the industrial waste load in terms of BOD.

Based on a BOD contribution of 0.17 lb/day/capita, the population equivalent of the 1959 sewage averaged 2,380,000.

On week ends and holidays, when most but not all industry is idle, the average population equivalent declines to 1,410,000. During the work week, Monday through Friday, the average population equivalent is 2,860,000.

The connected population is estimated as 984,000, which indicates that the industrial waste population equivalent varies from 426,000 on a week end to 1,876,000 during the work week. During 1959 the average daily volumetric loading between week ends and work week varied from 147.2 to 187.4 mgd, a difference of about 40 mgd. Carried further, one can conclude that the additional 40 mgd of industrial wastes received during the work week contains an average of approximately 800 mg/l BOD and 665 mg/l suspended solids.

The existing treatment plant and 161 miles of intercepting sewers represent an investment of more than $70 million. Combined with the new treatment plant and interceptors in the aforementioned expansion program, the total investment in interceptors and treatment facilities will exceed $120 million.

To protect this investment, the Sewerage Commissions in 1958 adopted a complete set of rules designed to prevent misuse of the sewerage collection system and treatment plant. These rules combined existing rules and new rules covering all phases of operations, including industrial waste control.

The rules classify industrial wastes into three groups, as follows:

1. Wastes which cannot be discharged to any sewer or watercourse.

2. Wastes which, after pretreatment, must be discharged to watercourses.

3. Unpolluted waters, which must be discharged to watercourses.

Excluded Wastes

The wastes in Group 1 include wastes which may be altered by pretreatment to such an extent that they are acceptable in the sanitary sewer.

Of course, certain materials have been excluded from the sewer system. In regard to allowable concentrations, only three specific limits have been established, as follows:

1. A 100-mg/l limit on fats, oils, and greases.
2. A pH minimum of 5.5.
3. A temperature maximum of 140°F.

It has been recognized that wastes, such as plating and other metal finishing wastes, may require pretreatment; but maximum allowable effluent concentrations have not been set.

Most of the wastes specifically prohibited are relatively easily removed from a liquid industrial waste or are materials not generally found in a liquid waste. Garbage grinders are handled in a unique manner. Their installation is allowed in "homes, hotels, institutions, hospitals, catering establishments, or similar places where garbage originates from the preparation of food in kitchens for the purpose of consumption on the premises, or for consumption off the premises when served by caterers." This type of regulation was necessary to prevent the installation of large commercial grinders to dispose of solid industrial wastes in this manner. Although this regulation has been in effect for years, the Commissions are still contacted by large industries asking permission to grind solid wastes and discharge them to the sewer system.

Wastes Requiring Pretreatment

Wastes in Group 2 are those wastes which have a low BOD and after pretreatment will not be esthetically objectionable in a watercourse. At this point, the method of determining if a waste should be discharged to a watercourse or to the sanitary sewer should be explained. If an industrial waste, after pretreatment, has a BOD equal to or less than the sewage treatment plant effluent (15 to 25 mg/l) it is obvious that discharge to a watercourse is the logical solution. Discharge to a sanitary sewer utilizes interceptor and treatment plant capacity without reducing the BOD and actually accomplishes nothing except to change the point of waste discharge.

The lands adjoining many of the small watercourses in the district are owned by the County Park Commission and have been developed into parks or parkways. During dry periods, most of the flow in the smaller streams consists of waters which have been directed to the stream. As a result, there is a relatively low stream flow, which is easily affected by any failure of an industrial waste pretreatment unit.

In this regard, because direct connections to storm sewers and ultimately to watercourses are available on the plant grounds, a potential source of pollution is always present. This can take the form of a spillage, improper storage of material where drainage can reach the sewer inlet, or the worker who finds it easier to dump something in the sewer instead of disposing of it properly. All three types of discharges have occurred. The last, the deficient workman, is the most troublesome, because he is the hardest to locate and almost impossible to control. Generally, top industrial management has provided excellent assistance in locating and eliminating these sources.

Uncontaminated Wastes

Wastes in Group 3 are principally waters used for cooling purposes. These waters may come from wells, municipal supplies, or surface waters. Because they are not contaminated in the cooling process, unpolluted water has been defined as "water discharged

in its original state and water discharged which, after use for any purpose, is at least equal chemically, physically, and biologically to the water in its original state."

Control Program

The actual industrial waste control program can be broken down into two very general sections—new sources of wastes and existing sources of wastes.

New Waste Sources

The rules of the Sewerage Commissions require that all industrial waste pretreatment facilities must be approved by the Commissions before the local governing body can issue a permit for construction. Therefore, dependence is placed on the local plumbing inspection department to direct the plans or planners of the pretreatment facilities to the Commissions.

The principal problem, in regard to new plants, therefore, becomes one of determining which wastes require treatment and which do not, and after such determination is made, dissemination of the information to plumbing inspection departments, as well as to the engineers, architects, and plumbing designers. In this regard, the Milwaukee Commissions have an advantage over an agency covering a larger area, because all the work is confined to a metropolitan area served by local telephone service. When questions arise, an answer should be as near as the telephone.

As new industrial processes are introduced, surveys are conducted to determine what treatment, if any, should be required. For example, introduction of the diatomite filter for clarification of swimming pool waters presented a new waste for disposal—filter backwash water. The backwash waters from the filters were studied and it was determined that the spent diatomite and solids from the filter should be separated from the backwash water before it is discharged to the sanitary sewers. The studies led to the conclusion that the most practical method of treatment was a fill-and-draw type of batch treatment unit. After completing the studies, all plumbing inspection officials in the district and contract areas, as well as such other interested parties as architects, engineers, pool builders, and plumbing designers, were notified by letter that pretreatment facilities were required and that plans for such facilities must be approved by the Commissions.

Obviously, this portion of the control program requires close coordination with the local plumbing inspector, who must issue the local plumbing permit. If he should fail to recognize a potential industrial waste problem, the permit could be issued, construction completed, and the first indication of the industrial waste problem could appear as trouble in the interceptor system or the treatment plant. In actual practice, the local inspector correctly refers any questionable project to the Commission's office for a determination as to whether or not pretreatment is required.

Local designers are aware of the Commission's industrial waste control program and usually make contact during the planning period. This, of course, is the ideal situation, because the pretreatment facilities, if required, can be integrated into the over-all design.

A problem arises where a company with plants throughout the nation designs a plant for the Milwaukee area utilizing their regular consultants, and the first indication of the proposed construction is a call from the local plumbing inspector saying he is referring the plumbing contractor and the designer to the Commission's office. In this case, the designer has completed the plans, the bids have been let, and the plumbing contractor is now applying for the plumbing permit. Any change in the plans now is an

"extra" and is usually met with opposition by the designer.

For a big plant with a variety of wastes—some unpolluted waters, some requiring pretreatment before discharge to a watercourse, and others requiring pretreatment before discharge to the sanitary sewers—combined with an architect who is not industrial waste-minded, a series of problems usually exist.

The local plumbing inspector is expected to enforce the rules of the Commissions. For example, if a large supermarket is constructed, no pretreatment is required so no plans would be approved by the Commissions. The plumbing inspector would, however, be sure that unpolluted cooling waters from the air conditioning system and from the condensing unit of the refrigeration system were directed to a storm sewer. He would not allow installation of a central garbage grinder if such an installation was proposed. The Commissions would be consulted in this case only if the builder or owner questioned the authority of the plumbing inspector.

Existing Waste

The second section of industrial waste control concerns control of wastes from existing industrial plants and is, by far, the most difficult of the two.

It must be kept in mind that this is an industrial complex contributing more than 40 mgd of waste and about 65 per cent of the BOD received at the treatment plant on an ordinary weekday. The industrial plants are generally located in the Cities of Cudahy, Glendale, Milwaukee, Wauwatosa, and West Allis, and in the Village of West Milwaukee. When the industries were originally allowed to connect their wastes to the sewer systems, pretreatment to remove objectionable materials was required.

The tanning industry was required to provide screening to remove hair, leather scrap, fleshings, and other solids that would be retained on a ¼-in. mesh screen. The standard screen in use in the Milwaukee tanneries for the past 35 yr is a rotary screen in which the liquid passes through the ¼-in. screen and the solids are retained outside the screen and mechanically removed. The tanning industry has been greatly modified since these screens were installed due to changes in the tanning processes themselves.

The decline in vegetable tanning and lack of a market for animal hair have greatly modified the quantities and type of wastes one can expect from the tanning industry. When hair had a reasonable salvage value, it was reclaimed and thereby removed from the waste flow. Today, foam rubber materials have replaced hair and have so reduced the market for animal hair that most Milwaukee tanners do not attempt to salvage hair.

Because the hair is not salvaged, it is "burned" from the hides with a strong solution of sodium sulfite. This process reduces the time for hair removal from 10 days to 6 hr. It also results in the discharge of appreciable quantities of hair to the sewer system.

The chrome tanning process, which has replaced vegetable tanning to a large extent, utilizes sodium chromate and sulfuric acid instead of vegetable compounds. This reduces the tanning time from 3 months to 1 day. The net result of these process changes has been a great increase in production without an increase in plant floor space. Unfortunately, as is usually the case, waste treatment, being a non-profit process, has lagged behind other changes and the Milwaukee system is now at a point where additional treatment facilities or improvements of existing facilities are necessary.

The fine screens used in the plant in place of preliminary settling are very susceptible to clogging with hair, as it accumulates in the $\frac{3}{32}$- by 2-in. slots and in extreme cases must be removed by sodium sulfite treatment.

Malting wastes, consisting primarily of large volumes of concentrated steep waters, are another of the major wastes requiring pretreatment. These wastes, in addition to the soluble material, contain grains and other solids which are removed by screening prior to discharge to the sewer system. A major problem in the malting industry is to regulate the discharge of steep waters to prevent overloading of the pretreatment facilities and the sewer system. Steep tanks contain up to 67,000 gal of steep water and it is obvious that the discharge of a number of these tanks over a short period of time could result in surcharging of sewers in the vicinity of the malting operation. These discharges are required to be staggered to assure a waste discharge that will not exceed a specified rate.

Brewery wastes contain spent grains, hops, bottle labels, and broken glass, which must not be discharged to the sewer system. Broken glass originates in the bottle house and is easily removable in a glass settling basin. The spent grains are recovered and dried for sale as cattle feed. Hops are filtered from the wort and disposed of as a solid material. The bottle labels originate in the bottle house, where caustic soakers remove the labels from bottles before cleaning. These soaker wastes are then screened using drum or vibrating screens (slots $\frac{1}{8}$ by $\frac{5}{16}$ in.) to remove the old labels.

The meat packing industry is also an old established industry in the Milwaukee area, with two large and a number of smaller packinghouses located in the district.

Packing plants are required to remove grease, paunch manure, and other solid materials from the wastes prior to their discharge to the sewer system. Grease is usually removed by gravity-type separators, with or without mechanical skimming. Paunch manure originally was removed by storing in manure bins, which allowed the liquid to filter through the solids into the sewer system. The advent of the vibrating screen has changed this method of disposal. Paunch contents now are discharged to the vibrating screen and the solids discharged to a container for disposal, while the effluent is directed to the sewer. Stationary or rotary screens remove other solid materials from the remaining wastes prior to their discharge to the sanitary sewer.

Milk processing plants located in the district produce bottled milk, cottage cheese, ice cream, and other dairy products for direct distribution to consumer or to stores for resale.

Glass traps are required to prevent the discharge of broken glass from the glass bottling line, and a wax trap is required to prevent the discharge of wax from the paper carton bottling line. Separation of clear and contaminated waters is also required. In this regard, the wash-up water from the inside of delivery trucks is directed to the sanitary sewer. Tests of this waste indicated that it had a high BOD (180 to 2,400 mg/l) due to breakage of glass bottles or leakage from paper cartons. Whey from the cottage cheese operation is accepted in the sanitary sewer provided the minimum pH requirement (5.5) is satisfied.

Pretreatment facilities, which depend on mechanical equipment, are inspected weekly by Sewer Maintenance Department personnel, who observe the actual operation of the unit. This type of inspection establishes that the unit is in operation and has proved satisfactory in keeping the industrial waste section informed as to the performance of these units. Owners of the units are requested to report any mechanical failure of the pretreatment unit and the weekly inspection makes them more conscious of this requirement.

Location of Problem Sources

In common with all sewage treatment plants, there are problems in locating unknown sources of waste which are interfering with the treatment proc-

esses or are prohibited from the sewer system. A method of tracing these wastes has been developed utilizing the sewer maintenance personnel. Because all wastes entering the plant must come in from either the high- or low-level interceptor system, it must first be established at the plant itself the system which is carrying the objectionable waste.

In the case of an oil or grease, this can be done visually. If the material is suspended in the flow, an expanded metal screen provided with a heavy lead weight is effective in checking for coarse suspended solids in the sewage flow.

Once the interceptor system is established (high or low level), the general area in the system that is contributing the waste must be established. The maintenance personnel who are familiar with the interceptor system can quickly reduce the area in question if there is a continuous discharge of waste.

Intermittent discharges are the most difficult to locate. To demonstrate handling of an intermittent discharge of waste from an unknown source which was interfering with the fine-screen operation, an example of a recently completed case is cited.

During April and May 1959, heavy concentrations of solids were causing flooding of the fine screens between 8 and 9 PM when the solids bridged the $^{3}/_{32}$-in. screen openings, practically converting the screen into a filter. Microscopic examination of the solids removed from the screens indicated that wood fibers were the main constituents on each check, and in some cases the screenings consisted of almost all wood fiber.

Screening of the incoming sewage at the plant established that the wastes were coming in via the low-level system. This apparently eliminated the logical source of this type of waste, a large paperboard mill which the records indicated had been transferred to the high-level system in 1926. Because no other source which could contribute the large volume of solids was known, tracing of the wastes in the low-level system was undertaken.

On May 25, 1959, the maintenance department, using three crews equipped with expanded metal screens, started the check of the low-level system. Tracing had to be done in short steps, because the discharge was of relatively short duration and it was often impossible to tell if the crews lost the waste or if the discharge had stopped. Each evening progress was made, until on June 3 the waste was isolated in a section of the City of Milwaukee sewer system serving only the original logical source, the paperboard company.

Contact with the company confirmed what the tracing had established—that the company discharged wastes to the city low-level system as well as to the high-level system. It also was found that the board mill had no saveall system for the recovery of fiber. The system originally installed had been abandoned.

Evaluating the Industrial Waste Problem

The first step in evaluating the industrial waste problem was to survey the plant sewer system and determine which wastes went where. This is quite an undertaking in an old plant two blocks long and one-half block wide. The company cooperated with the survey crew in this undertaking, furnishing available prints, etc. All sewer lines were dyed with a sodium fluorescein solution (100 g/gal) and their point of discharge established.

On completion of the sewer survey, rectangular weirs and level recorders were installed in the four lines discharging to the high-level sewer and a flow record was obtained covering a one-month period. This first recording period was followed by a 56-hr sampling period in which samples were

collected at 15-min intervals, composited by 8-hr shifts, and analyzed in the laboratory. Spot samples were collected and settling tests were conducted during the 56-hr period.

The weirs and level recorders were left in place and two weeks later a week-end shutdown was sampled. Peak flows had been observed during the week-end shutdown and it had been decided to establish the waste quality during these peak flow periods, as they could be the deciding factor in the subsequent approval of plans for a waste pretreatment unit.

When the survey of the plant wastes was completed, a comprehensive report was written and all data from the flow gaging and sampling were attached. This report indicated that the plant discharged about 4.5 mgd of industrial waste containing roughly 24,000 lb of suspended solids and 14,000 lb of BOD. During the 3-hr shutdown more than 7,000 lb of suspended solids were discharged to the high-level sewer, along with an undetermined quantity to the low-level sewer.

This report was transmitted to the industry by the chief engineer, with a request that the company indicate within 30 days what steps would be taken to comply with the report's recommendation that pretreatment facilities to reduce the suspended solids discharged be provided.

The company indicated that it would proceed to provide the required pretreatment facilities and is at present modifying plant operations and designing the pretreatment facilities. If the company had not cooperated, it would have been necessary to issue orders under Chapter 336 of the Wisconsin Statutes. The company has also modified its operation to eliminate the batch discharges which originally led to the plant and were causing the most serious operating problems at the sewage treatment plant.

The survey of plant sewer systems is a valuable tool in the industrial waste control program, especially in the old plants where sewer plans usually do not exist. This type of survey has been utilized to locate clear waters surcharging to the sanitary sewer system. If this type of discharge is not voluntarily removed from the sanitary sewer system, removal is ordered.

At present, 15,700 acres (or about 20 per cent of the sewered area) is served by combined sewers. In these areas, no separation of clear waters can be effected, because no outlet is available. All new construction in the combined area must be done with future sewer separation in mind.

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AEROBIC BACTERIAL DEGRADATION OF GLUCOSE

A. W. Busch and N. Myrick

This paper is the third in a series reporting results obtained in an investigation of the biochemical degradation of organic compounds. The study was initiated on the postulation that there is no essential difference in the progression of bacterial growth over the broad range of environments encountered in industrial waste treatment and water pollution control. Thus there should be basic parameters relating the areas of pollution measurement, waste "strength," biological treatment, and receiving water self-purification. Investigators have generally approached these problems as separate entities. This paper presents theoretical and experimental evidence, supported by mathematical and biochemical formulations, of the interrelation of these areas of study.

The ultimate objective of this investigation is sufficient basic knowledge to permit formulation of an experimental procedure for a short-term BOD test broadly applicable to organic wastes of interest in water pollution control.

Theory

The first paper (1) in this series presented experimental data in support of the postulated theory regarding BOD progression in soluble substrates. The theory states that the process of biological oxidation of soluble organic substrates involves (*a*) conversion of the food material into cell substance with varying degrees of synthesis, and (*b*) utilization of stored decomposition products and cell substance. In this process a plateau of oxygen utilization representing conversion of all the substrate to bacterial cells occurs in 12 to 48 hr (depending on the analytical environment) and has a characteristic value for a specific substrate. This plateau should afford a much more valid point for determining total load or ultimate oxygen demand than does the conventional 5-day incubation. It was also pointed out that the only difference between the BOD bottle and the activated sludge process is concentration and hence time.

The second paper (2) reported an attempt to attain the ultimate BOD through respiration only, by blocking the assimilatory processes. This work served to verify the theory of BOD progression by producing plateau values representing a greater percentage of the ultimate BOD although an additional lag period was induced at critical concentrations of assimilation inhibitors.

The reproducibility of the plateau in oxygen utilization for a particular substrate has been mentioned previously. Workers in the field of microbiology have reported similar results in pure culture studies. In addition, investigators studying activated sludge have commented on the reproducibility of cell production under controlled experimentation. It follows logically that since the plateau in oxygen ultilization

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The paper was presented at the 15th Annual Industrial Waste Conference, Purdue University, Lafayette, Ind., May 3–5, 1960.

TABLE I.—Statistical Analysis* of Reproducibility of Short-Term BOD

Substrate†	Seed‡	BOD		σ		$\frac{\sigma}{M} \times \%$	
		36 hr	120 hr	36 hr	120 hr	36 hr	120 hr
Glucose	1	131.8	221.5	2.61	1.84	1.98	0.80
Glucose	2	132.0	220.6	2.09	2.67	1.58	1.21
Glutamic acid	1	123.7	217.8	2.57	2.03	2.08	0.93
Glutamic acid	2	123.0	217.8	2.37	2.05	1.93	0.94

* Each analysis based on 12 experiments of 3 dilutions each, *i.e.*, $N = 36$.

† All 300 mg/l.

‡ Seed 1—West University Place, Texas, sewage, 5 ml/l, filtered; Seed 2—Bellaire, Texas, sewage, 5 ml/l, filtered; dilutions used—5, 7, 9 ml 300 mg/l solution per bottle; substrate concentration—1.50, 2.10, and 2.70 mg/bottle (4.84, 6.77, and 8.71 mg/l).

in the BOD bottle represents conversion of substrate into cells there should be a correlation between short-term BOD and bio-oxidation solids production under conditions of similar solids age. Such a correlation, based on biochemical reactions, presupposes a permissible general formulation for cell material.

Experimental Procedure

The first step in the study was a statistical analysis of the short-term BOD test values for the two primary 5-day standards (Table I). Seed from two sources was utilized with each substrate. Each statistical analysis was based on 12 replicate runs using three substrate dilutions. Hence, N has a value of 36. The short-term BOD incubation period selected was 36 hr. This time was chosen on the basis of data (1) showing that for the substrate and seed concentrations in use, complete linearity for glucose was assured. For glutamic acid, 24 hr could have been just as well utilized.

The results of this statistical analysis show a maximum standard deviation of 2.61 for the 36-hr test and 2.67 for the 5-day test. Per cent errors show a maximum of 2.08 for the 36-hr values versus 1.21 at 5 days. "Standard Methods" (3) lists the 5-day BOD for a 300-mg/l glucose solution as 224 ± 11 mg/l and as 217 ± 10 mg/l for a 300-mg/l glutamic acid solution. The technique and accuracy thus appear satisfactory.

These data indicate that a plateau value of 132 mg/l for a 300 mg/l glucose solution is quite reproducible. This represents 41.1 per cent of the theoretical oxygen demand of the glucose.

The second step of the study was a delineation of the mode of solids synthesis in biological oxidation of glucose in exerting 41.1 per cent of the theoretical oxygen demand. Since the postulated theory holds that the plateau represents conversion of all substrate to bacterial cells, these cells should contain the remaining theoretical oxygen demand. Porges *et al.* (4) have suggested a general formula of $C_5H_7NO_2$ for mass mixed cultures. McKinney (5) has recently discussed the validity of this formulation as representative of young cells. The general reaction can be written as

$$A \cdot C_6H_{12}O_6 + B \cdot O_2 \rightarrow X \cdot C_5H_7NO_2 + Y \cdot CO_2 + Z \cdot H_2O \ldots (1)$$

Thus the cells should represent:

$$\frac{1 - 0.411}{1.414\,*}$$

= 0.416 g of solids per gram of BOD removed.

* $C_5H_7NO_2$ has a theoretical OD of 1.414 g/g.

The three possible modes of solids synthesis are: (*a*) synthesis of cells directly, i.e., growth only, (*b*) oxidative conversion into another carbohydrate; respiration only, or (*c*) a combination of growth and respiration.

Synthesis alone can be considered as:

$$C_6H_{12}O_6 + O_2 + NH_3 \rightarrow C_5H_7NO_2 + CO_2 + 4H_2O \quad (2)$$

However, this reaction indicates 0.591 g of cells per gram of theoretical oxygen demand and only 16.67 per cent of the theoretical oxygen demand is exerted.

Considering only respiration:

$$C_6H_{12}O_6 + (1-5)O_2 \rightarrow (5-1)CH_2O + (1-5)CO_2 + (1-5)H_2O \quad (3)$$

In this reaction solids production and oxygen utilization can proceed only in increments of 16.67 per cent which is not a multiple of 41.

Writing the reaction for a combination of respiration and growth:

$$8C_6H_{12}O_6 + 18O_2 + 4NH_3 \rightarrow 10CH_2O + 4C_5H_7NO_2 + 18CO_2 + 30H_2O \quad (4)$$

The reaction is governed by the respiratory quotient of glucose which has a value of 1. The equation shows: 0.195 g of CH_2O produced per gram of theoretical oxygen demand removed, 0.293 g of $C_5H_7NO_2$ produced per gram of theoretical oxygen demand removed, or a total of 0.488 g of solids produced per gram of theoretical oxygen demand removed, and 0.4 g or 37.5 per cent of the theoretical oxygen demand is exerted. At this point the substrate has obviously been consumed insofar as soluble BOD is concerned. However, as the stored carbohydrate is oxidized to cells,

$$6\,CH_2O + O_2 + NH_3 \rightarrow C_5H_7NO_2 + CO_2 + H_2O \quad (5)$$

an additional 0.122 g of cells is produced, which plus the 0.293 g of cells first synthesized yields a total of 0.415 g of cells as predicted by the short-term BOD experimental data. Furthermore, an additional 0.037 g of BOD is exerted which yields a total of 0.437 g or 41.0 per cent of the theoretical oxygen demand which is the plateau value of the glucose BOD progression.

A number of workers have formulated the mathematical expression for bacterial growth. Garrett and Sawyer (6) delineated a discontinuous function for non-flocculent cells in heterogeneous mass culture and showed no significant deviation from pure culture growth patterns. Gram (7) and McCabe (8) subsequently postulated mathematical models for the activated sludge process based on Garrett and Sawyer's results.

In the present study using very small initial concentrations of organisms as contrasted to the published mass culture work, the use of a continuous function identical to that used in forecasting the growth and limits of any biological population was elected. This procedure was tested by applying a continuous function composed of two exponential equations to three experiments selected from a two-year compilation. Figure 1 shows the experimental data used to evaluate the reaction velocity constants and the calculated data based on these constants. Note the divergent experimental environments represented. Substrate concentration ranged from 5.9 to 300 mg/l with seed concentrations of 5 to 200 mg/l; ranging from sewage to activated sludge. All seed was filtered through Number 2 Whatman paper to minimize predator and suspended solids interference.

On the basis of the data obtained, a summary of the postulated mathematical and biochemical progression of the aerobic bacterial degradation of glucose is presented in Figure 2. The coordinates y_0 and t_0 represent the first experimental analysis showing net oxygen uptake and hence growth. Although y_L is theoretically reached only at infinite time for the formulation pro-

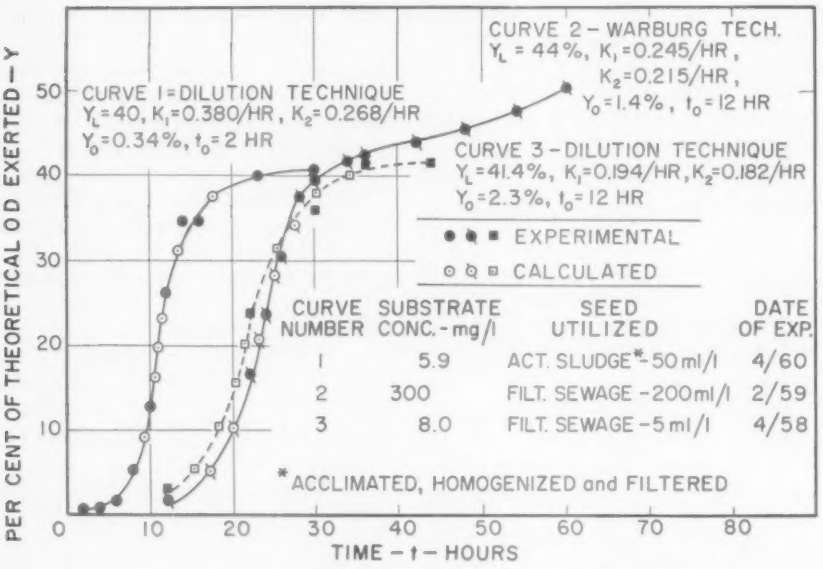
CURVE 2 – WARBURG TECH.
Y_L = 44%, K_1 = 0.245/HR,
K_2 = 0.215/HR,
Y_0 = 1.4%, t_0 = 12 HR
CURVE 1 = DILUTION TECHNIQUE
Y_L = 40, K_1 = 0.380/HR, K_2 = 0.268/HR
Y_0 = 0.34%, t_0 = 2 HR
CURVE 3 – DILUTION TECHNIQUE
Y_L = 41.4%, K_1 = 0.194/HR, K_2 = 0.182/HR
Y_0 = 2.3%, t_0 = 12 HR
EXPERIMENTAL
CALCULATED
CURVE NUMBER | SUBSTRATE CONC. - mg/l | SEED UTILIZED | DATE OF EXP.
1 | 5.9 | ACT. SLUDGE* - 50 ml/l | 4/60
2 | 300 | FILT. SEWAGE - 200 ml/l | 2/59
3 | 8.0 | FILT. SEWAGE - 5 ml/l | 4/58
* ACCLIMATED, HOMOGENIZED and FILTERED
PER CENT OF THEORETICAL O D EXERTED – Y
TIME – t – HOURS

FIGURE 1.—BOD progression curves for glucose at 20°C.

posed, the data approach sufficiently close to y_L to permit the use of the equation without significant error. As will be seen subsequently the two control points of 37.5 and 41 per cent are especially significant and can be experimentally substantiated in mass cultures.

If the curves described by the postulated continuous function were sym-

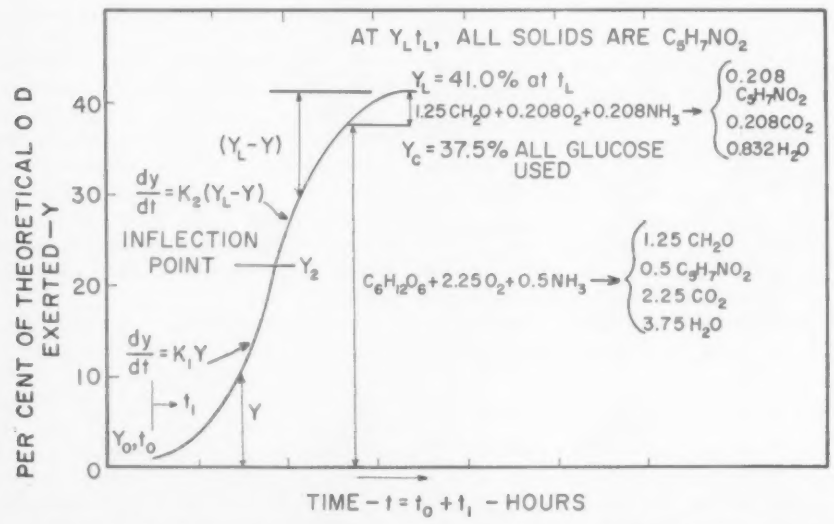
AT Y_L t_L, ALL SOLIDS ARE $C_5H_7NO_2$
Y_L = 41.0% at t_L
$1.25\,CH_2O + 0.208O_2 + 0.208NH_3 \rightarrow$ 0.208 $C_5H_7NO_2$, 0.208 CO_2, 0.832 H_2O
Y_C = 37.5% ALL GLUCOSE USED
$(Y_L - Y)$
$\frac{dy}{dt} = K_2(Y_L - Y)$
INFLECTION POINT
Y_2
$C_6H_{12}O_6 + 2.25O_2 + 0.5NH_3 \rightarrow$ 1.25 CH_2O, 0.5 $C_5H_7NO_2$, 2.25 CO_2, 3.75 H_2O
$\frac{dy}{dt} = K_1Y$
t_1
Y
Y_0, t_0
PER CENT OF THEORETICAL O D EXERTED – Y
TIME – $t = t_0 + t_1$ – HOURS

FIGURE 2.—Summary of experimentally verified mathematical and biochemical progression of bacterial degradation of glucose.

metrical about the inflection point, the average of k_1 and k_2 would represent the average growth rate and the mean solids age could be approximated. Since symmetry is not a necessary characteristic the mean solids age would be more nearly represented by $\bar{t}$, the time coordinate for the centroid of the area under the curve, measured from t_0. This value can be mathematically determined, with some effort, as shown in Figure 3. Data are plotted for the three experiments delineated previously in Figure 1.

As part of this research program, bench-scale completely-mixed bio-oxidation units have been operated continuously for more than 18 months. Experimental results from these studies have been presented in several publications (9) (10) (11). Figure 4 shows a summary of solids production data from these studies.

An interesting observation was the deviation of experimental data for batch systems without solids wastage from the projected and theoretical straight-line relationship. This is another indication of the fallacy in the misnomer of total or complete oxidation.

When the data of Figure 4 are converted into solids age by dividing the median mixed-liquor solids concentration by the median rate of solids production, the relationship shown in Figure 5 results. In contrast to Figure 2 wherein $\bar{t}$ represents mean solids age, Figures 4 and 5 show median data. The median is used here because the solids distributions were not all arithmetically normal and the median thereby becomes of greater statistical significance. The bench-scale data shown in Figures 4 and 5 are based on operational periods ranging from 30 to 103 days for each plotted median value.

The coordinates of the limit of the projected solids production curve are fixed at 0.707 g of solids per gram 5-day BOD removed and a solids age of 0.23 days. The solids production value is derived from Equation 4. The solids

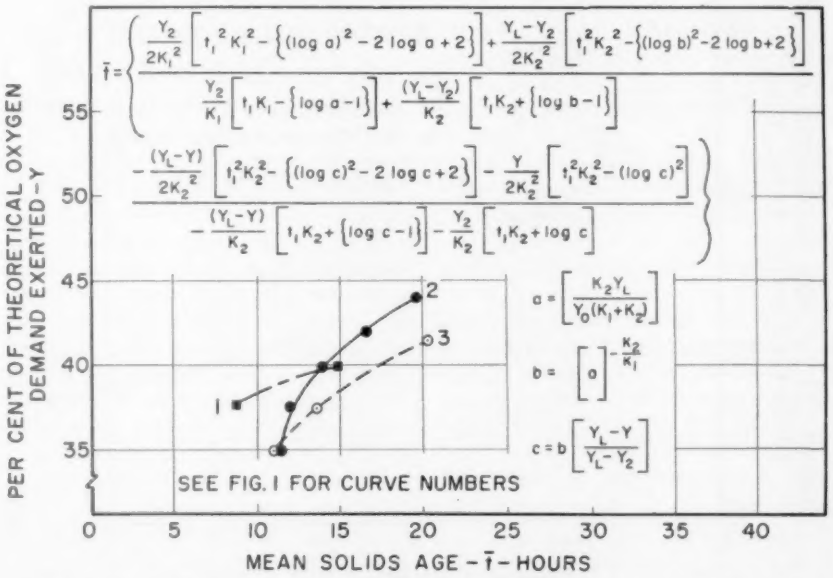

FIGURE 3.—Mathematical formulation for BOD progression vs. solids age at 20°C.

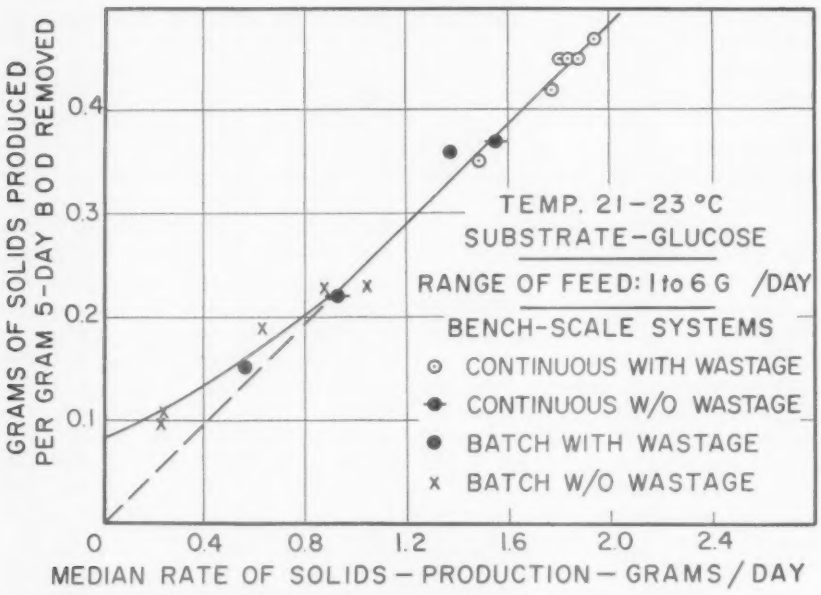

FIGURE 4.—Bio-oxidation solids production in completely-mixed bench-scale units in terms of g/day.

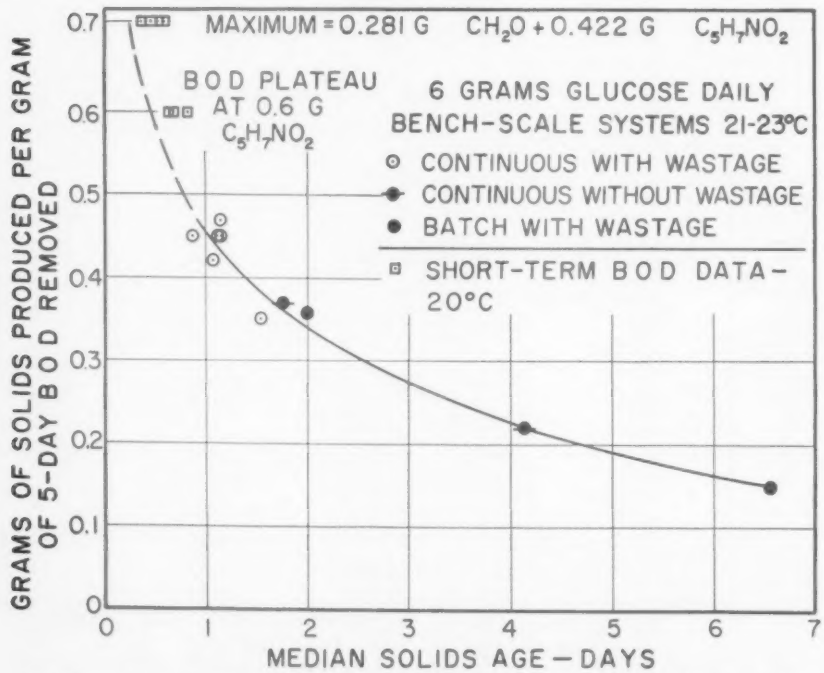

FIGURE 5.—Bio-oxidation solids production in completely-mixed bench-scale units in terms of solids age.

TABLE II.—Correlation of Short-Term BOD and Solids Production in Glucose Oxidation*

Conditions	Max Solids Production (At Max Carbohydrate)		Solids Production at Max Protein Level	
	Predicted	Observed*	Predicted	Observed*
Glucose conc., 500 mg/l, Warburg technique; sample vol., 40 ml; 500 mg/l×40 ml = 20 mg glucose = 21.4 mg theor. oxygen demand	21.4 mg/l×0.49 = 10.49 mg	265 mg/l×0.04L = 10.60 mg	21.4 mg×0.42 = 9.0 mg	164 mg/l×0.04L = 9.0 mg

* After data of Gaudy and Engelbrecht (12).

age is calculated from the data of Garrett and Sawyer (6) and Gaudy and Engelbrecht (12). These workers obtained a maximum growth rate of 0.18 per hour at 20°C for acclimated mass cultures in the oxygen utilometer and Warburg apparatus, respectively. The solids data of these investigators show 0.73 and 0.72 g/g 5-day BOD removed, respectively.

Also plotted in Figure 5 are the $\bar{t}$ and calculated solids production data based on the short-term BOD data of Figures 1 and 2. As is to be expected, the mean solids age for the BOD data is greater than the projected median solids age of the mass culture units. However, the general relationship of solids remaining versus solids age appears to hold in both mass culture bio-oxidation units and the short-term BOD progression.

The best evidence of the validity and reproducibility of the relationship between short-term BOD and bio-oxidation solids production is shown in Table II. Here data published by Gaudy and Engelbrecht (12) for Warburg studies using mass heterogeneous cultures of acclimated organisms are used to check the validity of predictions based on the theory presented herein. At the two check points of 37.5 and 41 per cent of the theoretical oxygen demand, predicted values of 10.49 and 9.0 are compared to observed values of 10.60 and 9.0 mg of solids produced per milligram of theoretical oxygen demand removed.

Discussion

The theoretical relationships presented appear to hold under both experimental and mathematical examination. The short-term BOD and bio-oxidation solids production correlation is especially gratifying in view of the temporal and physical separations involved. The correlated data were gathered over a span of nine years and several thousand miles under widely divergent climatic conditions. Apparently, heterogeneous cultures do follow the same metabolic and growth patterns regardless of areal political affiliations.

One prime result of the disclosure of a correlation between short-term BOD and bio-oxidation solids production should be the definition of the ultimate BOD of any soluble waste for which a plateau can be produced. Other intriguing possibilities are the determination of the maximum rate of oxygen uptake and the maximum solids production in the treatment of an organic waste by the simple mode of a one- or two-day BOD determination. These design parameters are completely unrelated to the engineering problems of clarification and hydraulic separation properties of a biological culture. However, it appears that the short-term BOD determination may

well supplant much laborious preliminary bench- or pilot-scale work in waste treatment design.

It is anticipated that the slight discrepancy between $\bar{t}$, the mean BOD solids age, and the median bio-oxidation solids age can be satisfactorily resolved by an acceptable mathematical manipulation. Current work is concerned with this and other aspects of the apparently wide applicability of the results of this study.

It is felt that these data can be used to support or explain published work apparently at conflict with accepted theories. A survey of such literature is, however, beyond the scope of this paper.

Summary

An experimentally verified theory of the mathematical and biochemical progression of the aerobic bacterial degradation of glucose is presented. A correlation of oxygen utilization, in the short-term BOD progression, and bio-oxidation solids production, as a function of solids age, is indicated. Substantiation of predicted solids production from the BOD test through the Warburg and oxygen utilometer to bench-scale completely-mixed systems is demonstrated, using the results of other investigators where applicable.

It appears that the short-term BOD test offers a mode of determination of ultimate BOD, maximum solids production, and maximum rate of oxygen uptake. The engineering design criteria regarding flocculation and settling characteristics cannot be predicted by batch techniques, however.

Conclusions

1. The aerobic bacterial degradation of glucose involves both cell synthesis and an oxidative conversion to carbohydrate which is stored in the cells and subsequently oxidized to cell material.

2. Maximum solids production corresponds to substrate disappearance and 37.5 per cent of the theoretical oxygen demand is exerted when the substrate is utilized.

3. Oxygen utilization continues at a declining rate until the stored carbohydrate is oxidized to cell material. The consequent sharp decline, or plateau, in the rate of oxygen utilization occurs at 41 per cent of the theoretical oxygen demand and is highly reproducible.

4. These points of 37.5 and 41 per cent of the theoretical oxygen demand can be used in conjunction with a solids production-solids-age relationship to define the theoretical oxygen demand of glucose.

5. The short-term BOD test offers promise of a mode of determination of maximum solids production and maximum rate of oxygen utilization.

6. The short-term BOD progression conforms to a continuous mathematical function defining the growth of any biological population limited by environment.

7. There is no significant difference in bacterial growth patterns over the broad range of substrate concentrations in the areas of pollution measurement, waste strength determinations, biological waste treatment, and receiving water self-purification.

Acknowledgment

The work reported herein was performed under N.I.H. Research Grant R.G. 5534.

Credit is due J. B. Weidler, Jr., for derivation of the equation and calculation of the plotted data of Figure 3.

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SEWER BOND SALES AND INTEREST

Date	Sewer Bond Sales ($ million)	Net Interest Cost of Sewer Bonds (per cent)	
		General Obligation	Revenue
1960			
Jan.	35.3	4.10	4.68
Feb.	37.2	3.65	3.98
Mar.	21.7	3.65	4.90
Apr.	43.2	3.70	3.90
May	23.2	3.79	4.53
June	36.7	3.91	4.09
July	55.5	3.74	—
Aug.	39.2	3.27	4.10
Sept.	30.3	3.42	3.77
Oct.	16.4	3.28	4.79
Nov.	26.3	3.33	4.01
Dec.	24.1	3.41	4.11
1961			
Jan.	41.1	3.48	4.41
Feb.	44.1	3.19	3.97
Mar.	36.7	3.49	3.68
Apr.	19.3	3.37	3.75
May	34.2	3.51	3.86

Data from WSPC Public Health Service.

ORP AND OPERATION

D. P. Backmeyer and Kenneth E. Drautz

One of the laboratory devices recently developed, and now available to the treatment plant operator, is the oxidation-reduction potential procedure. At Miami, this equipment has been found to be useful to the plant chemist and operator, as well as for research purposes. Henry (1) has described the instrument as it has been assembled in a field test kit, adapted particularly for use in sewage.

Recently the Miami sewage treatment plant has found many uses for this equipment. Oxidation-reduction potentials give the operator a direct insight into the treatability of the raw sewage entering his plant. The treatability of stale, septic sewage was discussed previously by Bargman *et al.* (2). At Miami, where the terrain is flat, and the temperature of the sewage is usually above 80°, stale, septic raw sewage is treated by the high rate or modified activated sludge process. Although the plant does not have primary settling tanks, land area and hydraulic design provide for future addition of these tanks, should they be required. Because of the expected weak sewage to be treated, and in order to minimize septicity of such a warm sewage, these tanks were not considered essential to the process. Variations in the degree of septicity of the Miami raw sewage are indicated by the potential readings shown in Table I.

Pretreatment

Pretreatment methods such as prechlorination and preaeration can be evaluated by the ORP test. Readings as low as − 300 mv usually indicate a poor condition of the sewage. Relatively large quantities of chlorine are required to raise the potential from these extreme low levels. The results of prechlorination at various rates at the plant grit chamber are given in Table II. Chlorination rates of nearly 9 mg/l show little or no beneficial effects. Obviously, it is economically unsound to apply the higher chlorine feed rate to the raw sewage at the grit chamber. Although grit is removed by use of air agitation, applied at 300 cfm for flows in the order of 25 mgd in the aerated grit chamber, little is accomplished in raising the ORP by this limited aeration provided.

TABLE I.—Septicity of Sewage as Indicated by ORP Readings on 13 Separate Days*

Period of Observation	Time of Reading	ORP, $E_{(cal)}$ (mv)		
		Min	Max	Avg
Jan–May 1960	2–5 PM	−420	−170	−303

* Electrodes were submerged at influent to plant grit chamber.

Activated Sludge

The maintenance of an aerobic environment for the sludge floc in an activated sludge plant is considered basic to the process. In dry weather periods, low dissolved oxygen is generally found in the aeration tank effluent liquor from 2:00 to 10:00 PM on Monday thru Friday. Here again, the ORP test is useful in showing the need for additional air during these periods. In many instances the process will

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TABLE II.—Prechlorination Results at Plant Grit Chamber for One Day at a Constant Flow Rate of 32 mgd. (Seven Samplings Between 11 AM and 4:10 PM)

Item	Rate of Chlorine Feed (lb/day)	Computed Chlorine Dosage (mg/l)	Raw Waste ORP, $E_{(cal)}$ (mv)	Grit Chamber Effluent* ORP, $E_{(cal)}$ (mv)
Min	900	3.36	−320	−300
Max	3,000	11.2	−280	−270
Avg	2,300	8.64	−296	−284

* Located downstream from point of chlorination.

function just as well with low residual dissolved oxygen as with higher levels. The ORP test shows the energy level, and the operator can adjust his plant to meet, if necessary, the minimum requirement for aeration of the sludge liquor. Potentials taken from samples of mixed liquor at the effluent end of one aeration tank and representing six scattered days of sampling between 10 AM and 4 PM show that the ORP varies from − 220 to + 160 mv, averaging − 43 mv. Dissolved oxygen (Winkler method) is normally found at an ORP of − 60 mv or above.

Recirculation

Most treatment plants have recycled liquors, i.e., digester supernatant, sludge concentrator overflow, elutriation tank effluent, and others, which may have appreciable impact on the basic treatment process. At Miami, these liquors are pumped directly to the aeration tanks. The effect of these flows on the high rate process can be carefully followed by ORP test work. Many times these liquors can be recycled when the raw sewage load is at a minimum for the day. This results in maximum economy of air usage, and may prevent periodic overloads which result in poor quality effluents.

Sedimentation

In the final settling tanks, ORP readings will indicate the condition of the sludge in the tank bottom at the time the electrodes are submerged to the sludge level. Clarified liquors above the sludge blanket can also be examined. These latter readings will serve to forecast the postchlorination requirement of the final tank effluent, permitting adjustment of chlorine feed rates so that chlorination is adequate, but not excessive. Free chlorine residuals are found at about 220 mv $E_{(cal)}$. Postchlorination can be carried on at sub-residual levels by use of ORP control. By coordinating bacteria kill data with ORP information, the operator is able to utilize his chlorination facilities to the maximum advantage, from an economic standpoint.

Lift Stations

The relative septicity of the raw sewage at the pump stations on the Miami mainland has also been investigated by ORP tests. The treatment plant is located on a 65-acre tract of land on Virginia Key, about three miles off the mainland. Shock loads of septic sewage, the depletion of dissolved oxygen, and the start of hydrogen sulfide production can be determined. It is then possible to evaluate methods such as chlorination, or aeration, at strategic locations throughout the system, which could limit the degree of septicity.

The control of hydrogen sulfide formation by injection of compressed air into force mains has been described by Pomeroy (3). The use of this method in controlling hydrogen sulfide in the four-mile force main between the two large pumping stations on the mainland and the treatment plant on Virginia Key has been tried on an experimental basis. The entire control of this work was by ORP. The raw sewage contains no dissolved oxygen; it frequently is septic to the extent of hydrogen sulfide formation. Reduction of hydrogen sulfide, and subsequent further improvement of the raw sewage while in the force main can be

TABLE III.—ORP and Hydrogen Sulfide at Two Pumping Stations on the Mainland, and at the Treatment Plant Grit Chamber; Data Represents Sampling on Five Days*

Item	Fourth St. Pump. Sta.		Ninth St. Pump. Sta.		Treatment Plant Grit Chamber	
	ORP, $E_{(cal)}$ (mv)	Total Sulfides (mg/l)	ORP, $E_{(cal)}$ (mv)	Total Sulfides (mg/l)	ORP, $E_{(cal)}$ (mv)	Total Sulfides (mg/l)
Min†	−330	0.8	−380	1.2	−420	8.5
Max†	−200	0.6	−170	0.7	−260	5.4
Avg	−236	0.8	−254	1.0	−308	7.0

* Flow rates during sampling period averaged 32.7 mgd, making an approximate retention time in the force main, from pumping station to treatment plant, of 3.1 hr.

† Applies to ORP only.

followed by the ORP unit. Low readings, indicating sulfide present, can be augmented by other laboratory tests, such as total sulfide in the sewage, to further evaluate the changes taking place in the force main.

Table III presents data relating the sulfide in the sewage to ORP as determined at the pump stations and at the treatment plant on Virginia Key. Here again, the extreme septicity of the sewage is indicated.

To be of practical value to the plant chemist for portable use in his plant, the test equipment must be constructed of materials that require a minimum of maintenance. The equipment used at the Miami plant has proven to be rugged and reliable. It has been a useful tool for investigating many of the interesting problems encountered in operating the Miami high rate activated sludge plant.

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SMALL PLANTS IN METROPOLITAN SEATTLE

Frank J. Kersnar

The role of small sewage treatment plants in a metropolitan sewerage system is usually limited. In general, the most satisfactory and economic solution of the sewerage problems of a metropolitan area is achieved when sewage from the entire area is delivered either to a single point or to a relatively few points for treatment and disposal. As such, therefore, treatment plants serving metropolitan areas are relatively large and, in most instances, where small plants have been constructed in metropolitan areas, they eventually have been abandoned and the sewage flow diverted to the larger plants of the area.

Because of topographic conditions, several small plants are included in the master plan for sewerage of the metropolitan Seattle area. Provision of these plants, designed to serve small urban developments topographically isolated from the remainder of the area, was found to be more economical than transmission of the sewage flow to the major systems.

Location and Description of Metropolitan Area

The metropolitan Seattle area is located in the Puget Sound basin in the northwest corner of the United States. Bounded on the west by Puget Sound and on the east by the foothills of the Cascade Range, the metropolitan area is topographically an area of striated hills, rolling glaciated uplands, and deeply incised adjoining troughs. Its principal physical features, such as large lakes, major stream valleys, and intervening ridges, have a general north-south trend, paralleling the axis of Puget Sound.

For sewerage planning purposes, the metropolitan area may be regarded broadly as the area stemming from the central city, Seattle, and having common or topographically related problems. The area has a north-south dimension of over 40 miles and extends eastward from Puget Sound for a distance of 18 miles at the point of its greatest width. It encompasses an area of about 575 sq miles, or 370,000 acres.

In addition to Puget Sound, the principal physical features of the area are its rather rugged terrain, much of it heavily wooded, and its numerous lakes and rivers. Lake Washington, with a length of about 25 miles and an area of about 22,000 acres, practically bisects the area from north to south. In all, the many lakes and rivers provide about 140 miles of fresh-water shoreline.

Although it drains ultimately to Puget Sound, the metropolitan area is divided into four major watersheds. The largest of these, the Lake Washington watershed, encompasses almost 350 sq miles and thus constitutes about 60 per cent of the area. Only about 10 per cent of the total area drains directly to Puget Sound.

Compared with other metropolitan areas of the United States, the Seattle

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The paper was presented at the 33rd Annual Meeting of the Water Pollution Control Federation in Philadelphia, Pa., Oct. 2–6, 1960.

area is fairly new. Seattle, the oldest city, was incorporated less than 100 yr ago, while 12 of the remaining 20 cities in the area were incorporated during the past 15 yr.

Principal developments have largely centered in and around Seattle. Of the estimated 900,000 persons now residing in the metropolitan area, 550,000, or over 60 per cent, live in the city of Seattle. By the year 2000, however, development is expected to be such that only 36 per cent of the total predicted population of 1,740,000 will be in Seattle.

Existing Sewerage and Sewage Disposal

Responsibility for providing sewerage service in the metropolitan area is divided among 47 public, semipublic, and private agencies. Although these agencies operate 30 treatment plants, over half of the sewage generated in the area is discharged to various receiving waters without treatment.

Metropolitan Seattle Sewerage Survey

Continued deterioration of Lake Washington resulting from discharges of both treated and untreated wastewater and contamination of Puget Sound waters resulting from discharges of raw sewage led the city of Seattle, King County, and the State of Washington to initiate a survey of the sewerage problems and needs of the metropolitan area. This survey was conducted over an 18-month period in 1956 to 1958. The report of this study sets forth requirements with respect to trunk and intercepting sewers, main pumping stations, and sewage treatment and disposal facilities for each of the various areas making up the metropolitan Seattle area. In addition to estimated costs of needed improvements, the report presents long-range plans for their stage or step-wise construction and contains facts and conclusions relative to all the diverse physical, social, and economic conditions affecting formulation of the recommended program. A recommendation also is included for a central agency to be established for financing, constructing, operating and maintaining, and administering the proposed sewerage projects.

Formation of Metro

Pursuant to legislation enacted and approved in March 1957, any metropolitan area of the State of Washington containing two or more cities may organize as a metropolitan municipal corporation on vote of the people residing within the area. By a vote held on September 9, 1958, the people of metropolitan Seattle authorized the formation of a metropolitan municipal corporation empowered to perform the function of sewage disposal.

Immediately following the election authorizing its formation, the corporation began its organization and the governing body, the Metropolitan Council, was duly appointed as specified in the enabling legislation. The official name of the corporation, as adopted by the Council, is the Municipality of Metropolitan Seattle, commonly referred to as Metro.

Comprehensive Sewerage Plan

As a first step in implementing its powers relative to sewage disposal, the Metropolitan Council unanimously adopted a resolution establishing a comprehensive sewerage plan. The adopted plan is the plan of sanitary sewerage facilities recommended in the report mentioned above.

Under the comprehensive sewerage plan, metropolitan sewerage service is to be provided for the entire drainage area in which the municipality lies. Facilities to provide this service consist of two major and seven separate systems of trunk and intercepting sewers, pumping stations, and treatment and disposal works.

The two major systems, designated the Renton and West Point systems, will provide service for 334,000 acres, or 90 per cent of the total of 370,000 acres included in the service area. The remaining 10 per cent will be served by the seven separate systems, each consisting of trunk sewers and treatment and disposal facilities.

The Renton system is designed to serve the eastern and southern portions of the service area. Secondary treatment by the activated sludge process will be provided at the Renton plant. This plant will be constructed initially for an average sewage flow of 24 mgd and will be designed for enlargement to an ultimate capacity of 144 mgd. Effluent from the plant will be discharged to Duwamish River.

The West Point system is designed to serve the central and northern portions of the service area. The West Point treatment plant will provide primary treatment for an average dry weather flow of 125 mgd. Treated effluent will be discharged to Puget Sound through a 96-in. outfall extending approximately 3,900 ft offshore to a maximum water depth of about 190 ft.

The seven separate systems are designed to serve the western portion of the area. The areas which they will serve all drain directly to Puget Sound and are separated from the rest of the metropolitan area by a coastal ridge which runs in a general north and south direction and reaches elevations in excess of 500 ft.

Small Plants Included in Comprehensive Plan

The area to be served by the seven separate systems stretches along the entire western boundary of the metropolitan area and extends inland from Puget Sound a distance of approximately 5 miles at the point of its greatest width. The area is divided into north and south parts by the Salmon Bay waterway which connects Lake Washington to Puget Sound. The northern portion contains 6,350 acres, while the southern contains 30,020 acres.

The area generally slopes westward rather steeply to Puget Sound. Drainage to the Sound is through a number of small ravines and creeks, each of which is separated from the other by ridges exceeding 300 ft in elevation. Much of the shoreline along the Sound consists of steep bluffs and sheer cliffs, making it difficult, in most places, to provide for waterfront interception of sewage. Through the use of high-level interceptors, however, the sewage generated in the area can be concentrated at seven locations for treatment and disposal.

Development in the area has been entirely residential and future growth is expected to follow the same pattern. The sewage therefore is typically domestic.

During the course of the sewerage survey in 1956–58, economic analyses were made of various alternatives involving (*a*) treatment and disposal of the sewage from each individual area separately, (*b*) combining the sewage from two or more areas in a single plant, and (*c*) pumping of the sewage from each area to one of the major systems. In each instance, the most economical plan proved to be the one calling for treatment and disposal of the sewage from each area in its own separate plant.

The seven plants will all be located on the shores of Puget Sound and effluent will be discharged through submarine outfalls to the Sound. Analyses were made for each of the disposal sites to determine the degree of treatment and the length and depth of outfall necessary to insure adequate protection of the waterfront areas immediately onshore and in the vicinity of the discharge points.

The seven areas to be served by separate systems are designated as Redondo Beach, Des Moines, Miller

Creek, Southwest Suburban, West Seattle, Piper Creek, and Boeing Creek. The treatment plant for each of these areas is discussed below.

Redondo Beach

This area comprises the southwestern part of the metropolitan area. It contains 8,050 acres and will have a predicted population of 40,000 at ultimate development. Treatment for the sewage of the area will be provided in a primary type plant capable of accommodating an ultimate average dry weather flow of 5 mgd with a peak hydraulic capacity of 14 mgd. The plant will provide preaeration and sedimentation for the sewage with separate sludge digestion. Influent pumping will be required. Effluent will be discharged to Puget Sound approximately 1,500 ft offshore in water at a depth of about 120 ft.

Des Moines

Included in the Des Moines area is the Seattle-Tacoma International Airport. The total area is 7,520 acres and the population estimate for ultimate development is 60,000. Because of disposal conditions offshore from Des Moines, complete treatment will be required for an ultimate average flow of 6.5 mgd, with a peak wet weather flow of 16 mgd. Plant units will consist of influent pumps, preaeration and primary sedimentation tanks, trickling filters, secondary sedimentation tanks, and separate sludge digestion tanks. Effluent will be discharged to Puget Sound approximately 1,300 ft offshore at a depth of about 60 ft.

Miller Creek

The Miller Creek area contains 7,420 acres. The estimated saturation population of the area is 85,000. Treatment will be provided in a primary type plant laid out for an ultimate average flow of 7.5 mgd, with a peak hydraulic capacity of 18 mgd. Effluent will be discharged to Puget Sound approximately 2,900 ft offshore at a depth of about 200 ft.

Southwest Suburban

Sewerage service is presently being provided to the southwest suburban area by the Southwest Suburban Sewer District. Its area is 3,320 acres and the predicted ultimate population is 41,000. The existing plant provides primary treatment and has sufficient capacity for the expected ultimate average flow of 4 mgd and peak flow of 15 mgd. Effluent is now being discharged to Puget Sound through a 36-in. submarine outfall terminating at a depth of 60 ft.

West Seattle

The West Seattle area lies entirely within the city of Seattle and sewerage service is provided by the city. The predicted ultimate population of the area is 57,000 included in an area of 3,710 acres. The treatment plant is of the primary type with a capacity sufficient for the ultimate average flow of 7.2 mgd. The West Seattle area is served by combined sewers and, as a consequence, the peak wet weather flow to be handled is greater than would be encountered in a sanitary system only. The plant is designed for a peak wet weather flow of 60 mgd, at which flow the detention time in the sedimentation tanks is 30 min. Effluent is discharged to Puget Sound 1,400 ft offshore at a depth of 85 ft.

Piper Creek

The Piper Creek area is also entirely within the city of Seattle. It has an area of 3,000 acres and a predicted population of 25,000 at ultimate development. The area is served by the city of Seattle by a separate system and two small plants provide treatment. Neither of the plants is of sufficient capacity for the ultimate sewage flow

from the area. In addition, neither provides the degree of treatment required for the protection of the receiving waters. For these reasons, a new treatment plant of proper design and adequate capacity will be constructed to serve the area. At the new plant, primary treatment will be provided for an ultimate average flow of 3.5 mgd with a peak hydraulic capacity of 20 mgd. Plant units will consist of preaeration and sedimentation tanks, separate sludge digestion tanks, and other accessory structures and appurtenances. Effluent will be discharged to Puget Sound approximately 2,200 ft offshore at a depth of about 200 ft.

Boeing Creek

This area lies in the northwestern corner of the metropolitan area and comprises an area of 3,350 acres. The predicted ultimate population is 37,000. Treatment for the sewage of the area will be provided in a primary plant having a capacity of 3.2 mgd and a peak hydraulic capacity of 10 mgd. Effluent will be discharged to Puget Sound to a depth of 100 ft through a submarine outfall 1,600 ft long.

THE PRESIDENT'S WATER POLLUTION CONTROL ADVISORY COMMITTEE

The 9-man Presidentially-appointed Water Pollution Control Advisory Board joins with Dr. Luther L. Terry, Surgeon General of the Public Health Service (Chairman), several times a year to advise the Surgeon General on the administration of the Federal water pollution control program. Its appointed members represent the varied backgrounds and interests needed for a cross-section of top-level thinking in this responsibility.

The current membership of the President's Board are, in addition to the Surgeon General:

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FOAM FRACTIONATION FOR REMOVAL OF SOLUBLE ORGANICS FROM WASTEWATER

I. A. Eldib

The number and variety of soluble organic compounds of industrial origin found in bodies of water are producing an increased interest in their evaluation and control as contaminants. Among these organics are detergents, insecticides, herbicides, and solvents. Many are difficult to capture and identify, and they cannot be removed effectively by current treatment methods. Some do not respond to biological attack and they may, therefore, reach drinking water supplies. The most spectacular substances are those characterized by foaming.

A logical approach to the removal of dissolved organics which produce foaming is by the use of foam fractionation. This technique has been used in hydrocarbon as well as in aqueous systems. It has successfully separated some of the metal contaminants from petroleum (1), as well as fractionated complex heat sensitive protein materials from aqueous systems (2). Because of widespread interest in separating soluble organic compounds in wastewater, an evaluation of the foam fractionation procedure is believed to be timely. The purposes of this paper are therefore:

1. To review the literature on the nature of soluble organics in treated wastewater.
2. To describe what has already been done by foam fractionation for the removal of soluble organics from water.
3. To show, based on brief experimentation, the feasibility of foam fractionation for the removal of soluble organic contaminants from treated wastewater.
4. To define the areas of research which need to be investigated in order to define better the full potentialities as well as the limitations of foam fractionation in improving waste effluents.
5. To point out how foam fractionation could fit in the general picture of treating domestic wastewater and industrial waste streams.

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Background

Source of Organic Solubles

The contamination of water by organics originates from the waste chemicals of industrial plants, domestic sewage, natural run-off, and materials derived from the life cycle of aquatic plants and animals.

The complexities of disposal of wastes from the production of organic chemicals have been described by Carney and Hess (3). The residues from large diversified manufacturing processes may contain solvents of complex compounds including byproducts, process aids, unreacted raw materials, and the manufactured product itself. The volume of these wastes may be as large as that of the main product. Effective treatment methods for many of these complex materials remain to be developed. As mentioned earlier, some of the effects of the diverse mixtures of organic materials are taste and odor in water and interference with treatment of water for industrial and domestic use.

The organic chemicals occurring in water are usually present in very low concentrations, but a few thousandths milligrams per liter of contaminants may produce significant taste and odor. The low concentrations, complexities, and varieties of organic pollutants in water make the recovery and identification of these substances difficult.

Recovery of Organic Solubles for Identification

Methods for concentrating, isolating, and identifying the organic solubles have been reported by Middleton and Rosen (4). Exploiting the unique adsorptive properties of active carbon, a filter has been developed which adsorbs most of the organic materials from water. After water or wastes in quantities from 100 to several thousand gallons pass through the filter, the carbon is dried and the organic materials are extracted with chloroform or other organic solvents in a Soxhlet extractor.

The organic substances recovered from the carbon filter differ with the type of solvent used for the extraction. Chloroform, the solvent used in most studies, has been found to recover those substances principally responsible for undesirable taste and odor in water. Alcohol will remove a quantity of material equal to or greater than the amount recovered by the chloroform even after preliminary extraction by chloroform. These highly water-soluble materials recovered by the alcohol appear to have relatively little significance as taste and odor factors. Most materials investigated for the taste and odor effects are adsorbed quantitatively by carbon, but extraction by chloroform is only 65 to 80 per cent complete. Following extraction, the solvent is removed by distillation, and the residue is subjected to further analysis.

Soluble Organics as Water Contaminants

Some of the materials which have been isolated and identified are:

1. *Synthetic detergents.*—These materials are unique in that a good part of the product becomes a waste. Foam materials from Wheeling, W. Va. (4), were identified by means of infrared spectra as originating from synthetic detergents of the alkyl benzene sulfonate type (anionic). These substances are resistant to biological forces of purification in the stream and will survive usual water treatment processes although they are readily adsorbed by activated carbon.

A logical solution to this problem is for detergent manufacturers to use materials less resistant to biochemical action. Progress has been made along this line in the United Kingdom (5).

It has been stated that foaming, interference with coagulation, taste and odor production, and turbidity in water supplies are caused by synthetic detergents (6). In one instance it was thought that detergents from septic tanks migrated underground and appeared in water obtained from water wells several miles away.

2. *Insecticides.*—DDT is revealed by its infrared spectrum. Aldrin, a chlorinated hydrocarbon insecticide, was also isolated from a sample collected from the Snake River at Pullman, Wash. The chemical was found only once, and the estimated concentration was 0.001 mg/l. Such concentrations of insecticides are not considered hazardous to humans. However, toxicity to fish life may occur if water contains a few thousandths mg/l of some compounds such as endrin or toxaphene (7).

3. *O-Nitrochlorobenzene.* — Infrared spectra of the aromatic fractions of carbon filter chloroform extracts from Cape Girardeau, Mo., on the Mississippi River and at New Orleans were similar to those of o-nitrochlorobenzene. Tests show that coagulation and chlorination as practiced in water treatment plants would not reduce the concentration of the chemical from a 10-mg/l solution.

A few milligrams per liter of activated carbon removed the chemical (7).

4. *Phenyl ether.*—This material, by laboratory tests, has detectable odor when present in a concentration of 0.013 mg/l (7).

5. *Phenolic compounds.*—These have been recognized as being detrimental to water quality. They are associated with waste products from coke plants or refineries and other industries. However, phenolic pollution is more amenable to control at the water plant than other types of pollution (4).

6. *Petrochemical wastes.*—These include alcohols, benzene, ammonia, carbon black, acetone, aniline, styrene, and sulfur (4).

7. *Aliphatic and aromatic hydrocarbons.*—These materials have been isolated from drinking waters obtained from sources in the vicinity of petroleum refinery waste effluents (4). Materials found include substituted benzene compounds, kerosene, polycyclic hydrocarbons, and phenyl ether.

8. *Natural materials.*—Products of natural origin in water are frequently responsible for taste and odor difficulties. Waters from various sources have contained materials such as organic acids, ketones, and aldehydes. These result from natural decay, oxidation, and life and death processes of plants and other aquatic life.

Foam and Emulsion Fractionation

Techniques for Removal of Soluble Organics and Suspended Solids

1. *Foam fractionation.*—This technique provides a means of separating from liquids soluble compounds which are active at a gas-liquid interface; i.e., surface active compounds. When such a liquid is foamed, these active compounds will migrate to the surface or foam layer (foam). The concentration there will be greater than in either the residual liquid (foamate) or the original solution (feed).

2. *Emulsion fractionation.*—This technique provides a means of separating from organic liquids which are immiscible with water (e.g., hydrocarbons) soluble compounds which are active at the liquid-water interface; i.e., interfacially active compounds. When such a liquid is emulsified with water, these active compounds will migrate to the interface or emulsion layer. When the emulsion is partially broken, the concentration of the active compounds will be greater in the emulsion phase than in either the liquid or water phases.

3. *Froth flotation.*—Flotation is a method of concentration that consists of producing a hydrocarbon-like surface on nonhydrocarbon particles. The process is selective, the nonhydrocarbon particle in an aqueous solution becomes hydrophobic (water hating) and is removed from the water by being attached to rising bubbles of air. Of course flotation can also be used to remove suspended particles which naturally have a hydrocarbon-like surface.

Foam Fractionation vs. Froth Flotation

Foam fractionation should not be confused with froth flotation. Although they are mechanically similar (both involve the gassing of a liquid mass to bring about separation of the components), the two are different in principle.

Froth flotation deals with a heterogeneous system involving at least two, and usually three, distinct phases—a liquid and two different solids. Separation of the solids is achieved by modifying the particle surface characteristics of one so that it is more readily attached to air bubbles. Froth flotation employs an artificially magnified density difference between particles of different solids and is analogous in principle to separation by sedimentation.

Foam separation, on the other hand, is used to separate the components of a single homogeneous liquid phase. The material which ordinarily concentrates in the foam phase must have originally

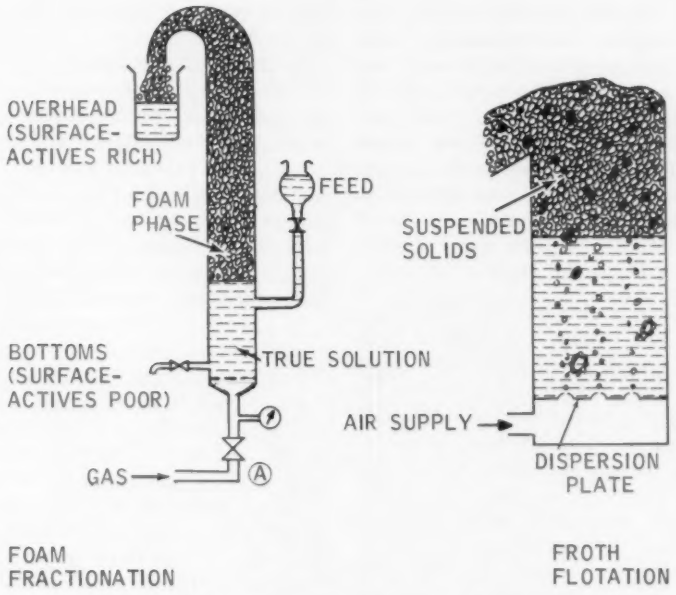

FIGURE 1.—Schematic differences in foam fractionation and froth flotation.

existed in true solution in the liquid medium. A diagram illustrating the differences between foam fractionation and froth flotation is shown in Figure 1.

The discussion in this paper will be aimed mainly at foam fractionation since, as will be pointed out later, it is most suited for removal of soluble organics rather than suspended solids either organic or inorganic.

The foaming apparatus consists of a column containing the solution to be foamed and a receiving vessel. In a batch-type operation, a gas (air, N_2, CO_2, or others) is bubbled through the solution to be fractionated, foam is generated, rises to the top of the column, is collected in a separate vessel, and is collapsed. Generally gas continues to be bubbled until no foam is formed. In a continuous operation, feed is introduced at the side of the column, overhead and bottom liquid fractions are collected separately. The liquid collected from the collapsed foam will be richer in the concentration of surface active components than the residual liquid or the original feed. In turn, the residual liquid will be poorer in concentration of surface active components than the feed.

Soluble Organics Removal by Foam Fractionation

A water-soluble organic molecule must contain a water-soluble group as well as a hydrocarbon-soluble group. The hydrocarbon-soluble end of the molecule will have little attraction for water and there will be a tendency for it to accumulate at the surface of the aqueous solution. Such molecules are known as surface active and will exert a surface pressure and lower the surface tension of the pure water (8).

The question therefore arises as to whether foam fractionation can remove only detergents since they are known to cause foaming. The answer is that foam fractionation will remove detergents as well as some of the other

water-soluble organic molecules. The soluble organics will naturally lower the surface tension of water and are, therefore, expected to concentrate in the foam. However, some soluble organics, especially those of low molecular weight, are not as surface active as detergents and may be difficult to remove by foam fractionation.

Review of Published Data

1. *Sewage treatment by flotation.*—Hansen and Gotaas (9) applied flotation to sewage treatment some years ago. Sewage flotation is a process for removing suspended and colloidal solids from sewage. The process consists of buoying the sewage solids to the surface by means of air bubbles. To facilitate the attachment of solids to air bubbles and the formation of a froth in which solids can be carried, it is necessary to add a frothing or foaming agent. Such agents are mainly heteropolar organic compounds containing hydroxyl (OH), carbonyl (CO), nitrile (CN), carboxyl (COOH), and amine groups in the molecule. The concentration of the flotation agent itself at the liquid-gas and solid interfaces promotes attachment of the particles to the air bubbles. These workers found lauryl amine hydrochloride extremely effective in reducing suspended solids by 95 to 99 per cent, bacteria by 99 to 99.9 per cent, and BOD by perhaps 50 to 80 per cent. It was, however, much less effective in removing the dissolved solids, either organic or inorganic. It effected a reduction of only 25 to 40 per cent. The cost of the additive was thought, however, to be high and apparently the work was not continued. Perhaps additional work with longer chain amines might have shown better promise. It cannot now be predicted from the data whether or not the removal of soluble organics would have been obtained without the addition of the lauryl amine hydrochloride, or without the presence of suspended solids in the system. The soluble organics removed also were not identified.

2. *Removal of proteins from aqueous solutions by foam fractionation.*—Concentration and purification of proteins and similar biological materials are examples of processes to which foaming has been applied. The extreme sensitivity of these substances to heat, pH, solvents, and other significant variables such as their high molecular weights, make these separations very difficult.

It has long been known that aqueous protein solutions possess appreciable foaming power and yield foams differing in composition from their bulk solutions. Some of the most recent work on the use of foam separations in the area of proteins is that by Gaden and Schnepf (10). In this work the effects of pH and concentration on the separations obtained by foaming aqueous solutions of the protein, bovine serum albumin and glucose polymer dextran were determined and found to be maximum at the isoelectric pH. At this point the protein exhibits highest surface activity with enrichment falling off with either increasing or decreasing pH. The enrichment ratio was also found to increase with decreasing bulk concentration. As expected, no enrichments were obtained for the dextran which exhibited no surface activity.

Similar work on the fractionation of proteins by foaming was carried out by Cohen *et al.* (2). These investigators conducted a series of experiments on jackbean urease with the view of ascertaining the effect of the pH of the medium, the protein concentration, and porosity of the foamer on the concentration of one of the components of a protein mixture (urease) in the foam. They found as did Gaden and Schnepf (10), that an optimum pH of the foaming medium exists. This optimum was found to be close to the isoelectric point of urease for various protein concentrations. As to the effect of protein concentration, unlike Gaden and Schnepf who found enrichment to in-

crease with decreasing concentration, they found in a range of 0.125 to 0.5 per cent by weight a distinct optimum (0.16 per cent) for both purification and recovery. Maximum purification was found with the foamer of finest porosity.

Proteins are found in sewage effluents and should be amenable to removal by foaming. This may be especially beneficial if bacterial decomposition is abandoned some day due to the resistance of some chemicals.

3. *Removal of alcohol from water.*—Gaden and Kevorkian (11) showed that alcohol in water can be concentrated in the foam phase. Their data show that by the use of a stage process, the alcohol can be removed completely from the water. Results typical of those obtained in foaming mixtures of isobutyl alcohol and water-saturated air (11) are shown in Figure 2. The solid curve represents data obtained for an alcohol-water solution foamed with completely humidified air. If on the other hand an air stream of lower humidity is used, a curve of the type dashed in Figure 2 is obtained. According to Gaden and Kevorkian, when the foaming gas is not saturated with volatile components of the mixture, they will be stripped out. In this case water, the more volatile component, was removed from the solution tending to enrich it in alcohol, while at the same time surface adsorption tends to enrich the foam. The two processes compete at rates dependent on temperature, solution concentration, and degree of saturation of the inlet gas. At some point during foaming, the two rates become equal and no enrichment is observed; then foam and foamate concentrations are equal. When the rate of water stripping exceeds the rate of enrichment of alcohol in the foam, the collapsed foam will be richer in water

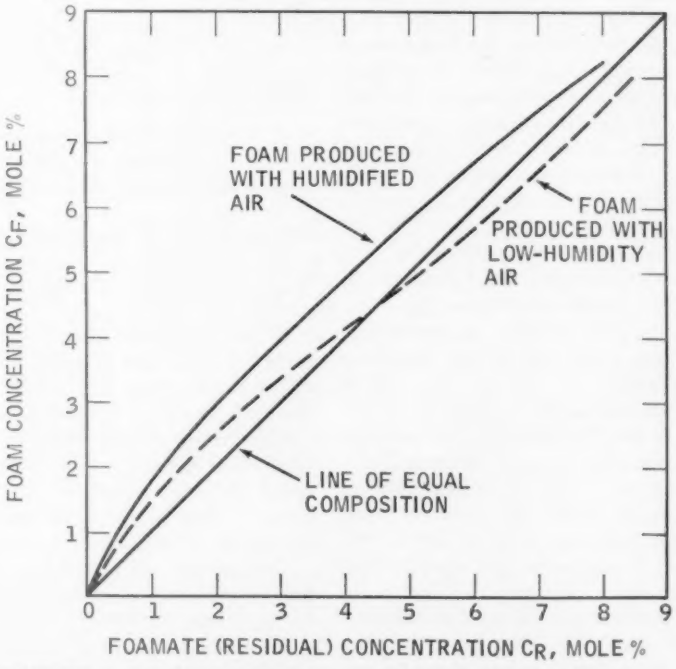

FIGURE 2.—Relation between foam and foamate concentrations in an alcohol-water system (from reference 11).

than in alcohol. This, of course, needs to be avoided.

Thus, in foaming solutions containing volatile compounds, varying the degree of saturation of the inlet gas stream permits a marked change in foam phase-residual liquid concentration relationships.

4. *Separation and concentration of bacterial spores and vegetative cells by foam flotation.*—A selective method of removing and/or concentrating bacterial spores and vegetative cells from the culture growth medium by foam flotation was described by Boyles and Lincoln (12). Here the authors do not distinguish between foam fractionation and froth flotation but combine both names and refer to the technique they used as foam flotation. Foaming chambers were made of simple glass cylinders equipped with spargers. In collecting spores of *Bacillus anthracis*, well autolyzed cultures were essential but cultures with high spore counts were not required in the culture containing bacterial cells. Several factors which are important in the foam flotation process were investigated in this study. Spores from autolyzed cultures of *Bacillus subtilis* var. Niger and cells of *Serratia narcescens* were collected more effectively with fine rather than with coarser spargers. The effect of pH, sodium chloride, and genetic colonial type on collection of spores was studied as well.

5. *Foam fractionation for removal of metal ions from radioactive wastes.*—Work reported by Gaden *et al.* (13) is on the foam separation of materials not normally surface active. The purpose of this work is to remove from radioactive wastes metal ions such as strontium and cesium. Since solutions of these metal ions are not surface active, the foaming of such solutions should yield no separation. To use foaming techniques for the separation of metals, the metallic ions must first be made surface active. This can be done by associating the metals in solution with some surface active material such as an anionic surface active agent, a chelating or complexing agent, or other negatively charged materials exhibiting surface activity. Solutions of varying strontium concentrations were foamed using Areskap 100 (a commercial anionic surfactant) as the foaming-complexing agent. Enrichment in the foam was observed and the enrichment ratio increased quite rapidly with decreasing concentration of strontium.

Recent Applications of Foam Fractionation

In order to carry out a separation by foaming or emulsification, the substance to be separated must lower the surface tension (air-water) or interfacial tension (hydrocarbon-water) of the bulk phase. Gibbs (14) predicted from thermodynamic considerations the increase in concentration of a single surface active material at an interface to be

$$\Gamma = -\frac{C}{RT}\cdot\frac{d\gamma}{dC} \cdots\cdots (1)$$

where

Γ = excess of solute per unit of surface, moles/sq cm;
C = concentration of solute, moles/cu cm;
$R = 8.3 \times 10^7$ dyne·cm/mole °K;
T = absolute temperature, °K; and
γ = surface tension, dynes/cm.

Gibbs' equation shows that enrichment at the interface is high when either the concentration of the solute in the bulk liquid, or the rate of change of surface or interfacial tension with concentration is high. When both factors are high, enrichment at the interface or depletion of the bulk solution increases as a function of their product.

To improve enrichment at the interface, a gas is dispersed in the solution to be treated. More surface will be created due to generation of foam thus providing more space for the surface active materials to reside.

Removal of Soluble Organics

A brief study was made to determine if foam fractionation can be used to remove soluble organics from a secondary wastewater effluent. The final effluent was from an activated sludge treatment plant handling domestic wastewater.

The secondary effluent was filtered through a Whatman filter paper No. 4 to remove any suspended matter. The filtered effluent was then blended in different proportions with distilled water. Surface tension and foam stability tests were made on the blends. The foam stability test consisted of shaking an effluent sample of 50 ml in a 100-ml stoppered graduated cylinder for 15 sec at about 2 strokes per second, with a stroke of about 2 ft. The time in minutes required for the foam to collapse was then used to measure the foam stability. The more stable the foam was, the longer it lasted before collapsing. The measurements illustrated in Figure 3 showed that the impurities in the effluent definitely reduce the surface tension of distilled water and cause it to foam. This, of course, indicates that these impurities can be removed by foam fractionation.

ABS Removal

Foam fractionation experiments were then carried out on the filtered secondary effluent. This was done by shaking a batch of the effluent in a separatory funnel, thus creating a foam layer above the liquid, waiting for the liquid entrained in the foam to drain down, withdrawing the residual liquid, and foaming it over and over. A diagram illustrating schematically the successive foaming operations is shown in Figure 4. The foam could have been generated by the use of a

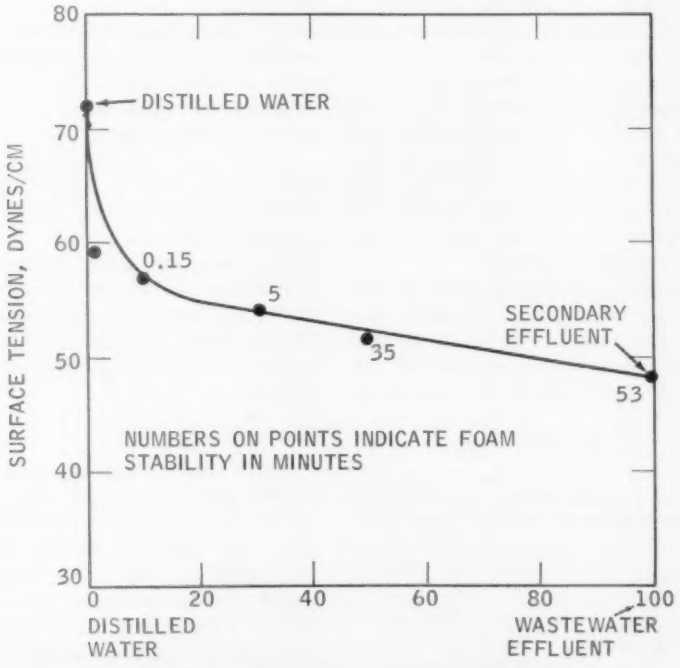

FIGURE 3.—Effect of surface active organic solubles in treated wastewater on surface tension of distilled water.

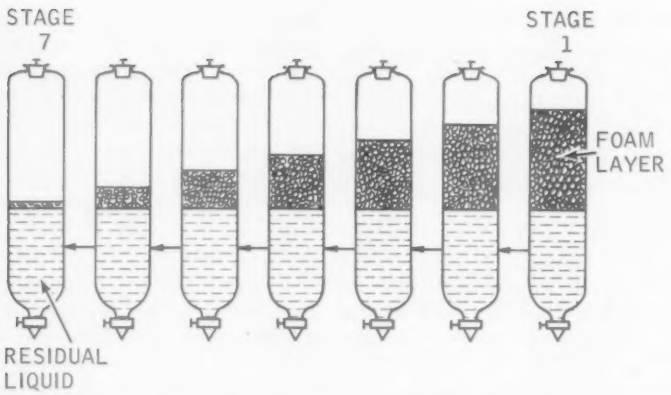

FIGURE 4.—Schematic diagram of successive foam fractionations.

foaming column similar to that described in Figure 1. However, since this work was of an exploratory nature, it was felt that simpler equipment such as that used here was adequate.

After seven stages of foaming it appeared that a very small foam layer was produced by shaking. Additional stages proved to be increasingly less effective with 20 stages producing about as much removal as seven stages. For example, after seven stages the surface tension was raised from 48.7 to 56 dynes/cm; after twenty stages, it was raised to 59.3 dynes/cm. The foam stability of the latter sample was one minute vs. 53 min for the untreated secondary effluent.

The treated effluent was analyzed for alkyl benzene sulfonate content and COD. The results (Table I) showed that foam fractionation removed 87 per cent of the ABS and 32 per cent of the COD.

If the loss of ABS (8.2) is multiplied by 2.0, since 1 mg of ABS is equivalent to 2.0 mg of COD, and the product 16.4 is subtracted from 22, it appears that other soluble organics which account for 5.6 mg of COD have been removed as well by foam fractionation. This indicates that foam fractionation can remove soluble organics other than detergents. Fortunately, the presence of detergents provides a stable foam with plenty of interface for weak surface active materials to concentrate.

TABLE I.—Removal of ABS and COD from Treated Effluent by Foam Fractionation

Sample	ABS (mg/l)	COD (mg/l)
Secondary effluent	9.7	68
Foam fractionated	1.5	46
Loss	8.2	22
Per cent reduction	87	32

There is no question that better results can be obtained by more carefully conducted experiments. For example, adjusting variables such as acidity, and bubble size, or using more efficient equipment to provide good drainage of liquid from the foam phase may either reduce the number of stages required or effect more complete separations.

Centrifuge Results

The filtered secondary effluent was centrifuged for about 5 min at forces of 200 times gravity. Very little sediment was obtained at the bottom of the centrifuge tube. The supernatant liquid was much clearer than the secondary effluent but had the same surface tension and foam stability. These results indicate that the foam precursors are soluble in the water or per-

haps colloidally dispersed. If they were not they would have appeared as sediment. A rise in surface tension and decrease in foam stability would have been observed as found following foam fractionation.

Other Areas for Treatment

The experiments discussed so far described the treatment of sewage effluents. Foam fractionation can also be used to treat industrial waste effluents. These effluents may be more concentrated with soluble organics than the sewage effluents. Examples of using foam fractionation on industrial wastes are:

1. *Removal of dyes from textile wastes.*—Some textile industry wastes contain dyes which may not be biodegradable or which may give water a color which makes it objectionable for drinking purposes. It is therefore desirable to remove them.

Organic dyes which are soluble in water generally reduce its surface tension. For example, measurements showed that very small amounts of patent blue dye,

$$[(CH_3)_2NC_6H_4]_2C=\langle\bigcirc\rangle=\overset{+}{N}(CH_3)_2Cl^-,$$

can reduce substantially the surface tension of water and cause it to foam. The results of these measurements are shown in Figure 5.

When a solution of 0.1 per cent by weight patent blue dye in water was foamed, the enrichment ratio was 100:1. In another experiment it was possible to remove the patent blue dye from a violet solution originally containing the patent blue and a red inorganic dye. At the end of the experiment, the violet solution turned red, and the collapsed foam collected overhead was deep blue. Obviously, the red inorganic dye stayed in the water because it is not surface active.

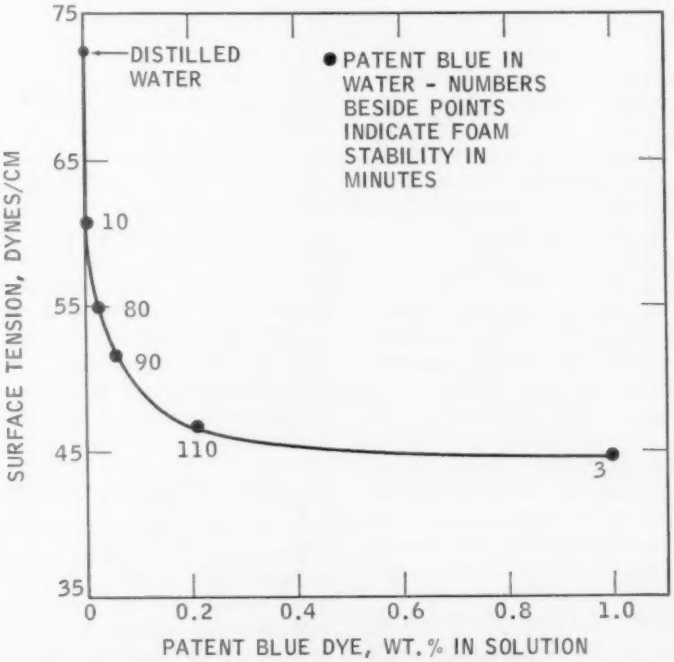

FIGURE 5.—Effect of patent blue dye on surface tension of water.

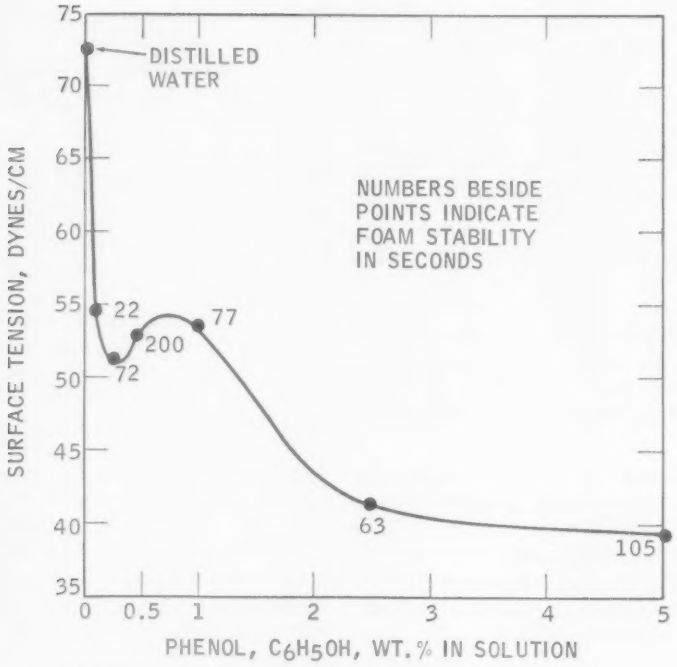

FIGURE 6.—Effect of phenol on surface tension of water.

2. *Removal of phenol from water.*—Phenolic compounds have been recognized as being detrimental to water quality. However, as mentioned earlier, phenolic pollution is more amenable to control at the water plant than are other types of pollution.

It is interesting to mention, however, that phenol causes water to foam and reduces its surface tension. This is shown in Figure 6. The inflection point in the surface tension concentration curve, or so-called minimum, has been observed and explained (15). The phenol-water solutions, however, had poor foam stability which indicate that phenol removal should be difficult. A discussion of the importance of foam stability on fractionation by foaming will be brought out later in this paper.

Potentialities of Foam Fractionation

In view of the encouraging results obtained so far on the removal of soluble organic pollutants from water by foam fractionation, more work is justified. This work should be directed toward defining the relative surface activity of the pollutants already identified. It should also define the effect on the separation of the different properties of the system or of the equipment. With this information at hand, it will be possible to better realize the potentialities and limitations of foam fractionation. Several of the important areas which need investigation are discussed in the following sections.

Properties Needing Investigation

1. *Surface tension concentration relationships.*—Since the organic soluble contaminants in water were proved to be of a wide variety, it is necessary to evaluate the surface activity of each type if at all possible. For example, several concentrations of a specific

class of organic contaminants (e.g., aryl alkyl sulfonates) should be added to distilled water.

The change of water surface tension γ with contaminants concentration should be a good guide as to the possibility of a successful separation by foaming. As stated earlier, better separations are obtained at higher $d\gamma/dC$. Foam stability measurements should also be made on each of the solutions prepared.

Of the known organic contaminants already identified in water, the proteins have been shown always to lower the surface tension of water. The ether extractables perhaps would not be as active as the proteins while the alcohol extractables would; these are more water soluble. Lignins lower the surface tension of water but are by no means as active as detergents. Carbohydrates, polysaccharides, and tannins should also be evaluated, since no background information is presently available of their effect on the surface tension of water.

2. *pH and ionic concentration.*—The hydrogen ion concentration can have a remarkable effect on foams. This variable has received a great deal of attention, and there are several controversial views on its effect. From this work it is believed that evaluating the effect of the pH of the medium on the success of a separation by foaming must be determined experimentally. However, for the purpose of orientation, it may be useful to point out the experiences of some earlier researchers.

In some cases, it was found that the hydrogen ion concentration has little effect on foams except on those produced with colloidal agents. These molecules can acquire electric charges which affect their solubility and distribution in the liquid phase. Protein foams generally exhibit maximum sta-

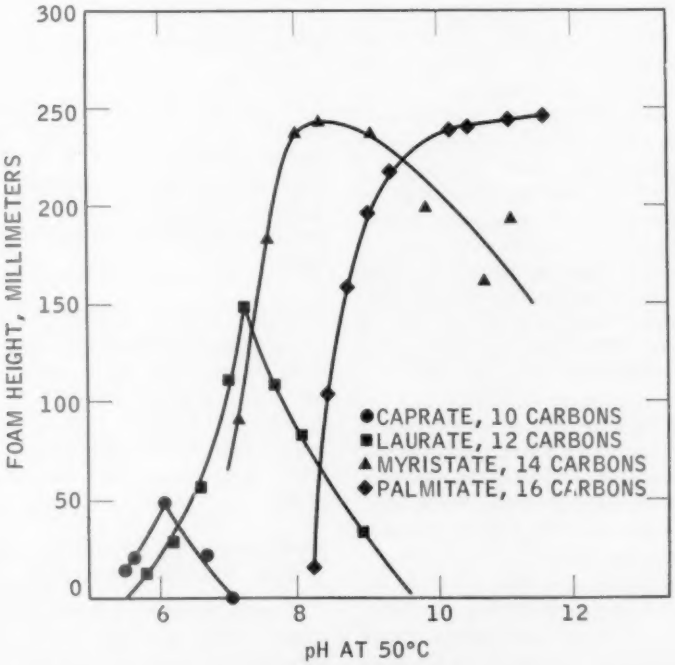

FIGURE 7.—Effect of pH on foam height (from Ref. 16).

bility at the isoelectric pH, which is also the point of minimum solubility. At this pH, maximum concentration in the foam took place (10).

Figure 7 represents the height of foam produced by the pouring of 0.1-per cent soap solutions at different pH values. The pH of the most voluminous foam increased from sodium caprate to sodium palmitate. A change by 2 pH units was sufficient to lower or increase the foam height severalfold (16).

It is understandable, of course, that because of limitations on the pH of the potable water, the researcher investigating foam fractionation may not be free to change at will the pH of the solutions in order to obtain favorable results.

3. *Solubility and surface activity.*— Solubility is related to surface activity. This is because solubility results from a molecule collecting in regions of the solution where it is most surrounded by the solvent liquid whereas, surface activity results from the molecules being least surrounded. For a surface active material, maximum surface activity is observed under conditions of minimum solubility. Unpublished data support these statements. In order for a successful separation of soluble organics from water to take place, it may be necessary to reduce the solubility of these organic compounds. This would be done by reducing the temperature at which the foaming is carried out or altering the pH if the latter has an effect on solubility. At these new conditions of minimum solubility, the decrease of surface tension of the water would be high and foam fractionation would be expected to be more effective. A change in the pH of the waste effluent may prove to be the most practical and least costly route.

In connection with the relation between solubility and surface activity, it can be deduced that the removal by foaming of certain homologues improves with increasing molecular weight. For example, for removal of alcohols, better results should be obtained by going from methyl, to ethyl, to propyl, to butyl, and so on.

Operating Variables and Equipment Geometry

So far the properties of the system which bear investigation have been outlined. Next is to define the effects of the operating variables and the equipment geometry, both, as will be seen from the following discussion, affect the separations. Some of the factors discussed below may not apply directly to the case where soluble organic pollutants are to be removed from water. They are included, however, to give the researcher investigating this new separation technique full awareness of the variables which can be used to improve the separations. Some of the observations reported were made in these studies and are not, therefore, documented by literature references.

Good Separation Requires a Stable Foam

Good separation by foaming requires a stable foam (i.e., one that does not collapse quickly after it is formed), since a finite time is required for the surface active materials to migrate to and concentrate at the gas-liquid interface.

Good Drainage of Foam is Essential

The bulk liquid carried in the foam must drain down the column in order for the overhead fraction to consist mainly of surface actives. It was found that at high gas rates, turbulence took place, and drainage was poor.

Enrichment by Foaming Increases With Area of Interface

If more interfacial area is created by foaming and generating bubbles, the enrichment (concentration in the foam/concentration in the liquid) should in-

crease in proportion to the increased area of a given mass of collapsed foam.

Temperature And Foam Stability

In addition to the effect already discussed, that low solubility enhances surface activity, and that this could be achieved by foaming at lower temperatures, temperature also has an independent effect on foam stability. This is tied in with viscosity of the solution. This is explained as follows: liquids must be reasonably viscous in order to minimize the collision and coalescence of bubbles. On the other hand, very viscous liquids do not foam. Experience has shown that foam stability is reduced at high temperatures and increased at low temperatures.

Staging May Be Essential For A Good Separation

In a fractionating column, the material collected as an overhead foam is that material which causes the bulk liquid to foam. Once a major portion of this material is removed, the foam stability of the bulk liquid drops drastically. In order to remove the last traces of a surface active material, a stable foam must be maintained. To do this, the residual liquid from a foaming operation can be re-foamed in a smaller diameter column.

Removal of Soluble Organics by Emulsion Fractionation May Be Expensive

As already stated, emulsion fractionation is a technique which provides a means of separating from liquids such as hydrocarbons, compounds which are active at the hydrocarbon-water interface. When the hydrocarbon is emulsified with water, these active compounds will migrate to the interface or emulsion layer. It is conceivable that if water contaminated with soluble or-

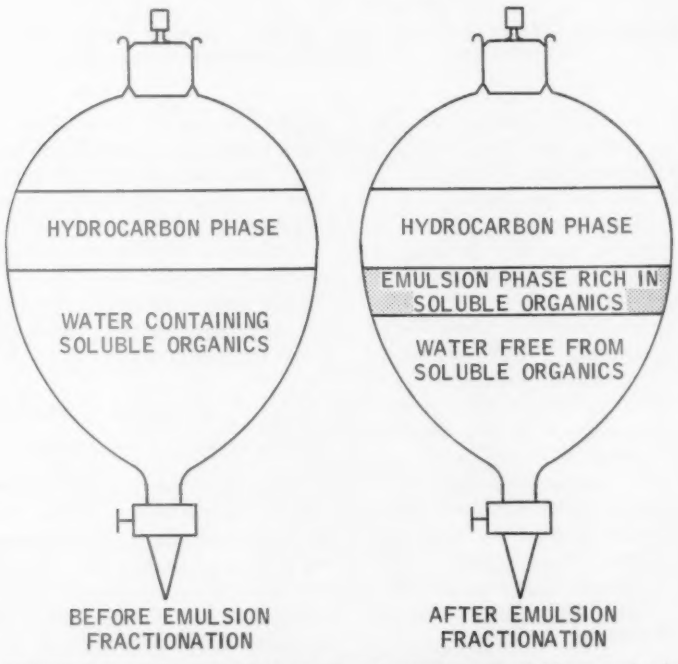

FIGURE 8.—Schematic diagram of concentration of soluble organics in emulsion phase following fractionation.

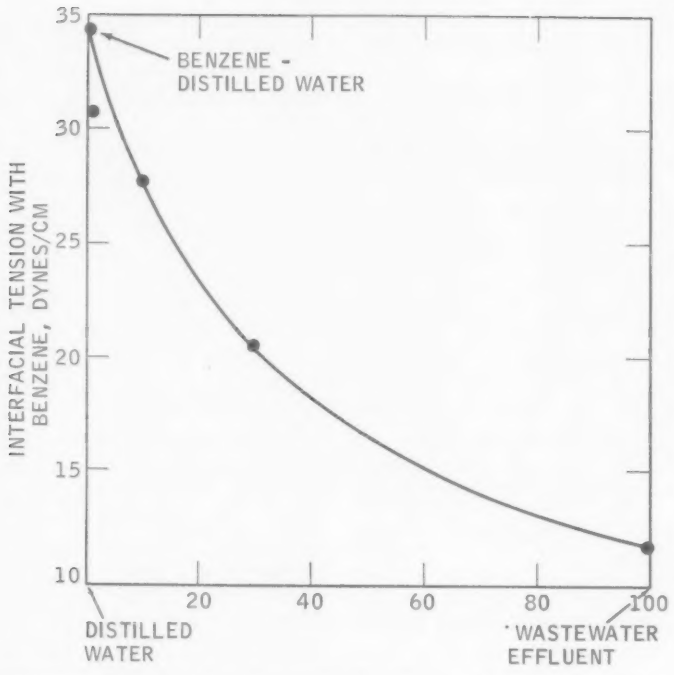

FIGURE 9.—Effect of surface active soluble organics in treated wastewater on interfacial tension of water with hydrocarbons (e.g., benzene).

ganics is emulsified with a pure hydrocarbon phase such as benzene or a petroleum naphtha, the surface active molecules in the water will be transferred to the emulsion layer. When the emulsion is partially broken, the concentration of the active compounds will be greater in the emulsion phase than in either the water phase or the hydrocarbon phase. The mechanism by which the soluble organics can be transferred from the polluted water to the emulsion phase is shown schematically in Figure 8.

Interfacial tension measurements were made on distilled water-secondary effluent blends similar to those described earlier. The organic solubles definitely reduced the benzene-water interfacial tension. The results are shown in Figure 9.

Although the measurements indicate that emulsion fractionation can undoubtedly remove the soluble organics from water, adoption of this technique may not be economical. Probably, large amounts of hydrocarbons will be required to emulsify the secondary effluent water. On the other hand, if the recovered hydrocarbon phase can be reused over and over, the economics may be more attractive. This approach needs further study.

Predicted Uses

Aerobic Tanks

Foam fractionation to remove the soluble organics can be achieved by skimming off the foam generated during the aerobic step in an activated sludge treatment plant. The foam layer is then sent to a vessel where it is collapsed either by heat or agitation (Figure 10). This arrangement is very convenient, since the air required to

create the foam is already available for the digestion.

It is conceivable that the geometry of the aerobic digestion tank, mainly due to the low ratio of height to diameter, may not allow for good foam drainage or enrichment of the rising foam bubbles. If this is the case, then the secondary effluent should be sent to a foam fractionation column installed in an arrangement similar to that described in Figure 11, and discussed in more detail in the next section.

Industrial Waste Applications

In this application, the soluble organics are generally concentrated, and foaming will, of course, be applied directly to the polluted streams prior to disposal in the municipal sewage or in surface water streams. Since the volume of effluent to be treated may be rather small compared to sewage effluents, a foaming column would be the most appropriate piece of equipment to use.

As shown in Figure 11, the foam fractionation plant would consist of a compressor, a gas saturator, a foaming column equipped with reflux, if necessary, and a foam breaking chamber. The polluted stream is fed continuously to the column, the foam phase rises to the top, is collapsed and collected, and the foamate or residual liquid free from most surface actives is withdrawn at the bottom of the column.

Destruction or Recovery of Organics

The collapsed foam from the aerobic digestion tanks, or from foaming columns used in improving industrial waste streams should be very concentrated with soluble organics. The organics concentrated can be destroyed by incineration following water evaporation, or can be oxidized to carbon dioxide plus water (17) (18) (19). Under certain circumstances, it may be profitable to recover some of the soluble organics by solar evaporation. These, if harmless in subsequent use, may be

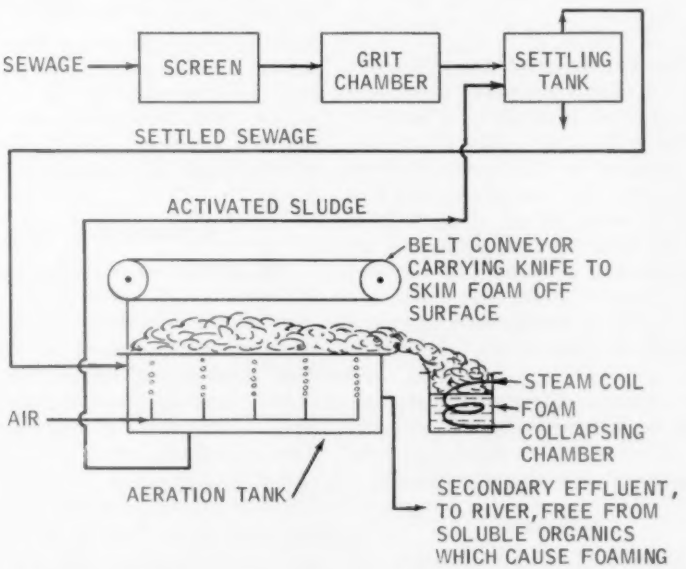

FIGURE 10.—Schematic diagram showing possible use of activated sludge aeration tanks as foam fractionators.

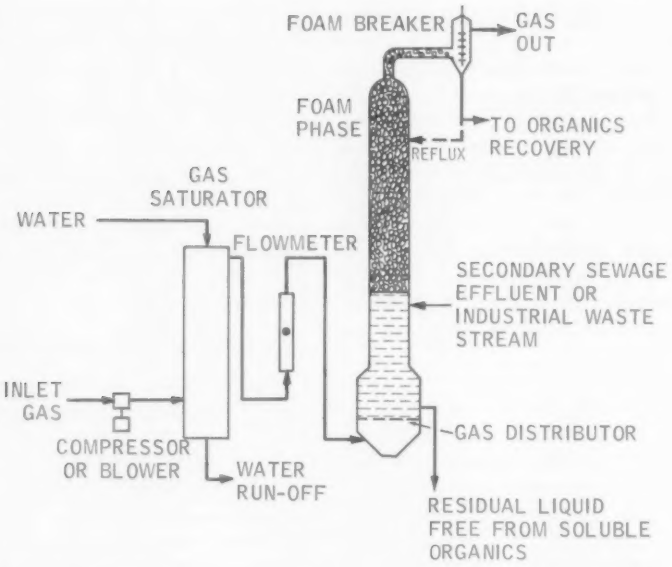

FIGURE 11.—Flow diagram for foam fractionator to remove soluble organics from secondary sewage effluent or industrial waste stream.

added to the humus-like material from the anaerobic digestion tanks and sold as fertilizer.

With Other Separations

If foam fractionation cannot remove all of the soluble organics, there is a possibility that it could be effectively combined with other removal or conversion techniques. For example, foam fractionation may be used as a first step to remove from sewage effluents high molecular weight surfactants such as detergents and proteins. It will not remove completely the low molecular weight soluble organics because they are weakly surface active. Examples are methyl alcohol, formic acid, and perhaps others. These can, therefore, be removed in a second step by adsorption from solution on activated carbon. The spent carbon is then regenerated.

Summary

Available data in the literature, as well as brief experiments in the laboratory, indicate that foam fractionation can be a useful technique for removal of soluble organic contaminants from treated domestic wastewater and industrial waste streams. More experimental work is needed, however, to define the concentration of soluble organics where foaming is not effective, also the types of organic compounds which cannot be removed by this technique.

Acknowledgments

The interest in contributing toward the solution of water pollution problems was inspired by contacts with scientists at the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. Bernard Berger was particularly instrumental in arousing enthusiasm to explore this field. Appreciation is also given to F. M. Middleton, Aaron A. Rosen, and David Stephan, all of the R. A. Taft Center, for their cooperation in supplying test samples and analyses.

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PATENT INFORMATION

Two pamphlets of interest recently have been issued by the Patent Office: "Obtaining Information from Patents," and "Answers to Questions Frequently Asked About Patents."

The first contains information as to obtaining patents, searching, and other services; the second contains the answers to 40 questions about patents most frequently asked.

Copies may be obtained from the nearest Field Office, U. S. Dept. of Commerce, or from the Office of Information Services, Patent Office, U. S. Dept. of Commerce, Washington 25, D. C.

COMPATIBILITY OF WASTEWATER DISINFECTION BY CHLORINATION

H. Heukelekian and S. D. Faust

The purpose of this paper is twofold: (*a*) to determine how well various treatment plants are meeting existing coliform standards for disinfection of sewage on the basis of available data, and (*b*) to determine what the bases and validity of these standards are.

To accomplish the first purpose, data on the residual chlorine and the coliform content of the plant effluents were collected from a number of treatment plants. Whenever chlorine dosage and contact time were obtainable, data on these two factors were also collected as collateral information.

Accomplishments

Collection of Data

Data that support the accomplishments of sewage disinfection by chlorination are not widely available from treatment plant records because coliform bacteria are not routinely determined in chlorinated effluents. Several sewerage authorities and individual treatment plants in New Jersey, Pennsylvania, and New York were contacted for such data with little success. Only 3 of the 96 sewage and industrial waste treatment facilities in New Jersey (1) using effluent chlorination were found to be routinely determining coliform bacteria, and one of the three had to be discarded because of its failure to quantitatively record the chlorine residual. The necessary data were, therefore, only available from the records of two New Jersey waste treatment plants that are under the jurisdiction of the Interstate Sanitation Commission (hereafter designated I.S.C.) and the New Jersey State Department of Health (hereafter designated N.J.S.D.H.). The 1953–1959 I.S.C. survey records of several treatment plant effluents constituted an additional source of information.

Methods of Analyses and Recording of Data

In all cases, the presence or absence of the coliform group of bacteria had been determined in five 1-ml portions of the chlorinated effluent in accordance with the current edition of "Standard Methods" (2). Consequently, the coliform data were examined for the number of samples showing 0, 1, 2, 3, 4, and 5 positive 1-ml portions. Chlorine residuals had been determined by the 5-min orthotolidine reading. Chlorine dosages were reported as mg/l whenever the records of rate of chlorine feed and flows were available. Detention times were based on the actual flow through the chlorine contact tanks, or on the time that the effluents were held in sample bottles before dechlorination.

Coliform Standards

The coliform standard included in the N.J.S.D.H. licenses to operate the two New Jersey waste treatment plants states, in effect, that coliform bacteria

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The paper was presented at the Annual Meeting of the Pennsylvania Water Pollution Control Association in University Park, Pa., Aug. 10–12, 1960.

shall not be present in more than one of five 1-ml portions in 80 per cent of the samples. This gives an approximate MPN of coliform organisms which, according to the five-tube per dilution table in "Standard Methods," equals 20/100 ml. Per cent compliance with the N.J.S.D.H. coliform standard, therefore, was calculated from the total number of samples showing zero and one positive 1-ml portions divided by the total number of samples times 100.

The I.S.C. coliform standard reads as follows: "All sewage discharged or permitted to flow into class 'A' waters of the District shall first have been treated so as to effect a reduction of organisms of the *B. coli* group so that the probable number of such organisms shall not exceed 100/100 ml in more than 50 per cent of the samples of sewage effluent tested by the partially confirmed test" (3). Routine survey analyses of the sewage treatment plant effluents provide for determination of the coliform group in five 1-ml portions. In accordance with the five-tube per dilution table of most probable number of organisms of "Standard Methods," compliance with the I.S.C. standard is constituted by the 0, 1, 2, and 3 positive 1-ml portions of any given sample. Per cent compliance was calculated from the total number of samples showing 0, 1, 2, and 3 positive 1-ml portions divided by the total number of samples times 100.

Results

Table I gives the chlorination of an effluent from the primary treatment of domestic sewages and industrial wastes by the Middlesex County, N. J., Sewage Authority (hereafter designated M.C. S.A.) in 1959 and 1960. Coliform data were available from a large number of samples that contained chlorine residuals from 0.0 to greater than 2.0 mg/l. Analyses of the data showed a range of 92.8- to 99.0-per cent compliance with the I.S.C. standard and a range of 82.1- to 92.8-per cent compliance with the N.J.S.D.H. standard. When the chlorine residual was recorded as 0.0 mg/l in 156 samples, the per cent compliances were 93.6 and 83.3, respectively. Likewise, when chlorine was present, compliance with the standards was met at all residuals. There appeared to be no stepwise increase in per cent compliance as chlorine residuals were increased from 0.1 to 2.0 mg/l. Average chlorine dosages ranged from 45.2 to 55.7 mg/l. In all cases, the samples were held for 30 min

TABLE I.—Disinfection of the Middlesex County Sewage Authority's Primary Treatment Effluent by Chlorination, 1959–1960

Chlorine Residual* (mg/l)	Chlorine Dosage (mg/l)		No. of Samples	No. of Samples† Showing						Compliance (%)	
	Range	Avg		0+	1+	2+	3+	4+	5+	I.S.C.‡	N.J.S.D.H.§
0.0	12.5–116.9	45.2	156	97	33	10	6	2	8	93.6	83.3
0.1	12.0–129.6	55.1	106	70	17	9	6	1	3	96.2	82.1
0.2	9.5–124.0	49.8	131	89	27	8	2	1	4	96.2	88.5
0.4	11.4–169.3	46.2	138	92	23	9	4	6	4	92.8	83.3
0.6	7.3–110.0	45.5	159	103	34	15	4	1	2	98.1	86.2
0.8	13.2–115.2	47.0	104	68	24	7	2	1	2	97.1	88.5
1.0	22.6–122.4	47.6	134	99	24	9	0	0	2	98.5	91.8
1.6	22.4–116.6	54.2	96	69	19	5	2	1	0	99.0	91.7
2.0+	13.4–236.8	55.7	221	165	40	9	3	2	2	98.2	92.8

* Orthotolidine chlorine residual, 5-min reading.
† Samples held in bottles 30 min to allow for detention time in outfall.
‡ Coliform standards set by Interstate Sanitation Commission.
§ Coliform standards set by New Jersey State Department of Health.

TABLE II.—Survey of Chlorinated Primary Treatment Plant Effluents by the Interstate Sanitation Commission, 1953–1959

Plant	Chlorine Residual* (mg/l)	No. of Samples	No. of Samples Showing						Compliance (%)		Contact Time (min)§
			0+	1+	2+	3+	4+	5+	I.S.C.†	N.J.S.D.H.‡	
A	0.0–1.0	15	1	0	3	1	0	10	33.3	6.7	3
	1.1–2.0	26	6	3	1	4	6	6	53.8	34.6	3
	2.1–3.0	19	9	3	3	2	0	2	89.5	63.2	3
	3.1–5.0	16	10	2	2	0	1	1	87.5	75.0	3
B	0.0–0.5	28	2	5	1	1	4	16	28.6	25.0	10
	0.6–1.0	10	5	4	0	1	0	0	100.0	90.0	10
	1.1–2.0	15	10	2	1	0	0	2	86.7	80.0	10
	2.1–5.0	5	5	0	0	0	0	0	100.0	100.0	10
C, F	0.0–0.5	21	6	5	1	1	1	7	61.9	52.4	20
	0.6–1.0	12	6	3	0	0	1	2	75.0	75.0	20
	1.1–2.0	26	16	8	1	0	0	1	96.1	92.3	20
	2.1–5.0	29	23	6	0	0	0	0	100.0	100.0	20

* 5-min orthotolidine reading.
† Coliform standards set by Interstate Sanitation Commission.
‡ Coliform standards set by New Jersey State Department of Health.
§ Length of time samples were held in bottles to compensate for detention time in outfall pipes.

before analyses in order to allow for detention time in the outfall pipe.

Table II gives the results of a survey of four primary treatment plants by the I.S.C. for the years 1953–1959. To meet the I.S.C. coliform standards, plant A required a chlorine residual range of 1.1 to 2.0 mg/l; plant B, 0.6 to 1.0 mg/l; and plants C and F, 0.0 to 0.5 mg/l. Before analysis, the samples were held in the bottles for periods of 3, 10, and 20 min, respectively. Similarly, two secondary treatment plant effluents given in Table III met the standards with 0.6- to 1.0-mg/l chlorine residuals when the samples were held for 20 min. For purposes of comparison, the per cent compliance with the N.J.S.D.H. standards also are given in Tables II and III.

Table IV gives the results of effluent disinfection of an activated sludge treatment plant operated by the Bergen County, N. J., Sewage Authority

TABLE III.—Survey of Two Secondary Treatment Plant Effluents by the Interstate Sanitation Commission, 1953–1959

Chlorine Residual* (mg/l)	No. of Samples	No. of Samples† Showing						Compliance (%)	
		0+	1+	2+	3+	4+	5+	I.S.C.‡	N.J.S.D.H.§
0.0–0.5	25	0	2	2	1	0	20	25.0	8.0
0.6–1.0	21	8	0	2	2	3	6	57.1	38.1
1.1–2.0	29	13	2	5	2	1	6	75.9	51.7
2.1–5.0	13	9	2	0	1	0	1	92.3	84.6

* 5-min orthotolidine reading.
† Samples held in bottles 20 min to compensate for detention time in outfall pipes.
‡ Coliform standards set by Interstate Sanitation Commission.
§ Coliform standards set by New Jersey State Department of Health.

TABLE IV.—Disinfection of the Bergen County Sewage Authority's Activated Sludge Treatment Effluent by Chlorination, 1953–1958

Chlorine Residual* (mg/l)	Chlorine Dosage (mg/l)		Contact Time (min)		No. of Samples	No. of Samples Showing						Compliance (%)	
	Range	Avg	Range	Avg		0+	1+	2+	3+	4+	5+	I.S.C.†	N.J.S.D.H.‡
0.0	2.0–5.3	3.7	20.0– 34.8	29.5	11	1	5	2	1	2	0	81.8	54.5
0.1	2.0–5.9	3.6	19.3– 65.2	34.9	22	8	11	3	0	0	0	100.0	86.4
0.15	1.7–8.0	3.8	22.7–173.8	34.5	20	4	14	2	0	0	0	100.0	90.0
0.20	2.0–7.6	3.7	13.0– 86.9	34.1	59	24	25	7	1	1	1	96.6	83.1
0.3 –0.35	1.9–6.4	3.8	22.7– 47.4	31.2	19	8	6	3	1	0	1	89.5	73.7
0.45–0.75	2.5–7.1	4.5	22.7– 47.4	33.2	16	6	7	2	0	1	0	93.8	81.3

* 5-min orthotolidine reading.
† Coliform standards set by Interstate Sanitation Commission.
‡ Coliform standards set by New Jersey State Department of Health.

(hereafter designated B.C.S.A.). Compliance with the I.S.C. standard was met in 82 per cent of the samples when no chlorine was detected, and in 97 per cent of the samples when 0.1- to 0.75-mg/l residuals were recorded. On the other hand, the N.J.S.D.H. standard was not met in the absence of chlorine in 11 samples and when 0.3- to 0.35-mg/l residuals were detected in 19 samples. Compliance with the N.J.S.D.H. standard was met, however, when 0.1- to 0.2- and 0.45- to 0.75-mg/l chlorine residuals were recorded in 117 samples. No significant stepwise increase in per cent compliance with the two standards occurred when the chlorine residuals were increased from 0.1 to 0.75 mg/l. In all cases, the average contact times ranged from 29.5 to 34.9 min. The average chlorine dosages ranged from 3.6 to 4.5 mg/l.

Discussion

Accomplishment of sewage disinfection by chlorination is variable under treatment plant conditions of operation. The usual procedure measures accomplishment by either of the following parameters: (*a*) analysis for coliform bacteria in the effluent to determine compliance with standards set by regulatory agencies, and (*b*) chlorine residual. The type of sewage treatment, chlorine dosage, and contact time are factors that must be considered in effluent disinfection.

A summary of the data in Table V

TABLE V.—Summary of Data Showing Compliance with Coliform Standards

Plant Effluent or Literature Reference	Chlorine Residuals (mg/l)*		Contact Time (min)	Compliance (%)	
	I.S.C.*	N.J.S.D.H.†		I.S.C.	N.J.D.S.H.
Prim. effl. (Plant A)	1.1–2.0	>5.0	3	53.8	—
Prim. effl. (Plant B)	0.6–1.0	0.6–1.0	10	100.0	90.0
Prim. effls. (Plants C, F)	0.0–0.5	1.1–2.0	20	61.9	92.3
Sec. effls. (Plants D, E)	0.6–1.0	2.1–5.0	20	57.1	84.6
Prim. effl. (M.C.S.A.)	0.0	0.0	30	93.6	83.3
Sec. effl. (B.C.S.A.)	0.0	0.1	33	81.0	86.4
Raw sewage (Ref. 5)	1.0–1.5	>2.0	95–135	—	—
Plant effls. (Ref. 4)	0.84–1.5	—	—	—	—

* O-tolidine chlorine residuals required to meet Interstate Sanitation Commission coliform standards.
† O-tolidine chlorine residuals required to meet New Jersey State Department of Health coliform standards.

shows that the per cent compliance with the I.S.C. and N.J.S.D.H. coliform standards varies from plant to plant. No generalizations can be made with regard to type of treatment as a factor affecting compliance, because the effluents of both primary and secondary plants meet the coliform standards under a wide range of chlorine residuals. In other words, per cent compliance is not favored by one type of treatment over the other. Primary treatment plants can meet the standards in the absence of chlorine or in the presence of chlorine residuals ranging from 0.5 to greater than 5.0 mg/l. Secondary treatment does not alter the compliance in either direction. The B.C.S.A. secondary effluent also can meet the I.S.C. standard in the absence of chlorine and the N.J.S.D.H. standard with 0.1 mg/l residual. On the other hand, to meet both coliform standards the two secondary plant effluents under the jurisdiction of the I.S.C. require 0.6 to 5.0 mg/l residuals. It can be said, therefore, that compliance with a coliform standard can be met with various types of sewage treatment, but not always under constant conditions of chlorine residual.

These observations generate speculation as to why compliance is not affected by type of treatment. Strict attention to the operation of disinfection may supply the answer. The M.C.S.A. and B.C.S.A. are known to be well-operated treatment plants with respect to control of disinfection. Samples are taken at regular intervals and analyzed for coliform organisms as well as chlorine residual. Appropriate changes in disinfection operation are dictated by these results. On the basis of a large number of samples, therefore, these two plants can demonstrate compliance with coliform standards under conditions of little or no chlorine residual. On the other hand, the A through F treatment plants do not routinely determine coliform organisms, but instead depend on residual chlorine to control disinfection and to evaluate accomplishment of disinfection. These plants show a variance in the per cent compliance under a wide range of chlorine residuals, whereas the M.C.S.A. and B.C.S.A. are in close agreement on per cent compliance with little or no chlorine present.

Compliance, or even per cent compliance, with coliform standards cannot be predicted on the basis of chlorine residuals. Table V shows quite a variance of chlorine residuals needed for compliance. The observation that no chlorine residual is necessary for compliance disagrees with the results of Hess *et al.* (4). On the basis of a linear correlation statistical analysis of 5,000 samples from 100 treatment plant effluents, Hess found that it was necessary to maintain chlorine residuals in the range of 0.50 to 1.5 mg/l in order to meet the I.S.C. coliform standards.

On the other hand, the data show that residual chlorine is needed in treatment plants A to F to meet coliform standards. These observations are in agreement with the results of Hess *et al.* (4) and Pierce (5). On the basis of their data, it is necessary to maintain chlorine residuals in excess of 0.5 mg/l to meet the I.S.C. and N.J.S.D.H. standards. This can also be attributed to control of disinfection by residual chlorine instead of the coliform test.

Furthermore, a significant stepwise increase in the per cent compliance cannot be obtained with a stepwise increase in chlorine residual after the coliform standard has been met. This is demonstrated by the M.C.S.A. and the B.C.S.A. data (Tables I and IV) where the per cent compliance does not show a significant trend toward stepwise increase as the chlorine residual is increased.

An actual or even a stipulated range of chlorine residuals, therefore, is not a reliable parameter for determining or controlling the accomplishments of disinfection. There is ample evidence

to demonstrate compliance with a given coliform standard both in the absence and the presence of residual chlorine. Similarly, there is evidence to show that the presence of a chlorine residual does not insure compliance in all cases. For example, the N.J.S.D.H. standard would not have been met with chlorine residuals as high as 5.0 mg/l (Table II, Plant A) and 2.0 mg/l (Table III). There are, however, a greater number of compliances than non-compliances with the two coliform standards when the chlorine residual exceeds 0.5 mg/l. In addition, a specific chlorine residual cannot insure a stipulated per cent compliance with a given coliform standard, as demonstrated by the M.C.S.A. and the B.C.S.A. data. A situation, therefore, exists whereby compliance, as well as non-compliance, can be demonstrated in the absence and presence of residual chlorine.

Heukelekian and Day (6) have shown that contact time is a factor affecting the number of coliform organisms remaining in plant effluents and the per cent compliance with a coliform standard. It was observed that if the effluent requirements were a maximum of 250 coliforms per 100 ml, o-tolidine chlorine residuals of 0.05 to 0.15 mg/l could not produce effluents of low coliform densities with a contact time of 15 min. Residuals of 0.2 to 0.5 mg/l produced a 50-per cent compliance with a 15-min contact time and an 80-per cent compliance with a 30-min contact time. In general, the data in Table V are in agreement with the effect of contact time on the compliance with the I.S.C. coliform standard. A greater percentage of the samples complied with this standard after 30 and 33 min than after 3, 10, and 20 min. It appears, however, that chlorine residual rather than contact time determines the per cent compliance with the N.J.S.D.H. standard in Tables II and III.

On the basis of the foregoing, the accomplishments of sewage disinfection can be evaluated better by the determination of coliform organisms than by the determination of chlorine residual. By virtue of a single test, the operator can determine the absence, presence, or numbers of coliform organisms in the chlorinated test. In addition, the results of a large number of coliform tests can be translated directly into compliance or non-compliance with a coliform standard. The operator is able, therefore, to demonstrate accomplishment of disinfection rather than to speculate on the basis of chlorine residual.

On the other hand, the operator has to be able to control disinfection as well as know of its accomplishments. Disinfection is usually controlled by the chlorine dosages and by the chlorine residuals needed to produce an effluent that will satisfy a stipulated coliform standard. It is necessary, therefore, to determine the coliform organisms and chlorine residual of each plant effluent under various chlorine dosages. Once these operating conditions are established, the operator can effect daily control of disinfection by the appropriate changes in chlorine dosage to maintain the desired residual compatible with the coliform standard of the effluent. The operator must continue, however, to make periodic determinations of coliform organisms to assure adequate disinfection.

Objectives

The per cent compliances with the coliform standards of the two regulatory agencies were discussed after it was shown that only a limited number of plants actually attempt to establish compliance on the basis of coliform tests. The control of disinfection is most commonly made by residual chlorine, which may or may not correspond to the required coliform standard. The validity of the various coliform standards thus requires attention.

The objective of sewage disinfection is to destroy the enteric pathogenic or-

ganisms that may be present in order to make the receiving body of water safe for the various uses to which it is put. The aim is not sterilization and destruction of all the organisms. Immediately, therefore, the following questions arise: (*a*) Which organisms are to be destroyed? and (*b*) To what extent should they be destroyed to eliminate any possible public health hazard?

From the qualitative standpoint, the following pathogenic organisms may be found in sewage: (*a*) cholera vibrio, (*b*) typhoid and paratyphoid bacteria (*Salmonella*), (*c*) dysentery bacteria (*Shigella*), (*d*) amoebic dysentery (*E. histolytica*), (*e*) tuberculosis bacteria (*Mycobacterium tuberculosis*), (*f*) viruses causing infectious hepatitis and poliomyelitis, and (*g*) parasitic worms, such as roundworms and tapeworms (*Helminths*), hookworm, *Ascaris*, and *Shistosoma*. It is recognized that these organisms differ in their resistance to germicides in general and chlorine in particular. Cholera is a non-existent disease in the United States and is not likely to be present in sewage; but if it were present, ordinary sewage chlorination would destroy this pathogen. Similarly, the typhoid, paratyphoid, and dysentery bacteria can be readily destroyed by the chlorine dosages and residuals commonly used in sewage disinfection; these organisms are killed somewhat more readily than the coliform bacteria. *Mycobacterium tuberculosis* has been found in sewage, especially from sanatoria. A residual of 2 mg/l with a contact time of 30 min is required for effective destruction of this bacterium (7). Viruses are also highly resistant to chlorine. It has been shown that the virus of infectious hepatitis survived a chlorine residual of 1 mg/l and was inactivated with 15 mg/l of residual chlorine after 30 min (8). To destroy cysts of *E. histolytica*, 3 mg/l of free residual chlorine are required at pH 7.0 (9). The eggs of parasitic worms, especially *Ascaris*, are very resistant to chemicals and disinfectants (10).

That chlorination as generally practiced does not destroy the tuberculosis bacteria, viruses, cysts of amoebic dysentery, and parasitic worms is apparent. This is not as serious as it might appear to be because, with the exception of infectious hepatitis, the other enteric diseases, the causative organisms of which are not destroyed by the usual chlorination practice, are not common in the United States and are removed by other methods of sewage treatment such as sedimentation, coagulation, and filtration.

The pathogenic enteric organisms that are destroyed by the common practice of sewage chlorination are, therefore, those causing typhoid and dysentery. In the control of disinfection, however, these organisms are seldom enumerated. The number of coliform organisms is used as an indication of the efficiency of disinfection and the elimination of these pathogenic enteric bacteria. It was found, despite a concerted effort, that very few plants in New Jersey control their disinfection by the enumeration of coliform organisms, and thus the plan of obtaining data from a great number of plants on the accomplishments of chlorination in terms of coliforms was frustrated. The disinfection that is generally based on residual chlorine is, therefore, three steps removed from the primary objective of the destruction of enteric pathogenic organisms. Furthermore, there is ample evidence in the literature to indicate poor correlation between chlorine residuals and survival of coliform organisms. There is no real assurance, therefore, that the maintenance of a certain chlorine residual will correspond to the required coliform counts in the effluent.

The coliform determination test includes several species of bacteria with varying sanitary significance, the two most common of which are *E. coli* and *A. aerogenes*. *A. aerogenes* is less

numerous in excreta and is commonly found in soil; *E. coli* is more abundant in excreta, but are not all of fecal origin. The coliform test does not differentiate between fecal and non-fecal types; neither does it eliminate the more abundant soil organism *A. aerogenes*.

The common standard for the coliform content of effluents in New Jersey is that in five 1-ml portions inoculated, the confirmed test should not be in excess of one positive in 80 per cent of the time. The validity of this standard is open to some question from the standpoint of the primary objective of disinfection; namely, the destruction of enteric pathogenic bacteria, which chlorination, as practiced, is capable of eliminating for the protection of public health. To what extent should sewage be chlorinated? What number of coliforms in the effluent is compatible with the elimination of the typhoid and dysentery bacteria in the effluent? Because in practice these organisms are seldom enumerated, assumptions must necessarily be based on the available information and the results considered on a conservative basis.

Coliform organisms in sewage range from 100,000 to 1 million per ml (on the basis of 400 billion coliform/day/capita and 100 gpd/capita of sewage). For the sake of calculation, the higher value is taken. Kehr and Butterfield (11) established the ratio between the number of typhoid bacteria and *E. coli* in polluted waters to be a function of the prevalence of typhoid fever in the contributing population. On the basis of available literature, they arrived at a ratio of typhoid organisms to *E. coli* at different levels of incidence of typhoid fever, as follows:

Incidence—Annual Death Rate per Million Population	Typhoid Bacteria per Million *E. coli*
5.0	6
10.0	9
50.0	19
100.0	26

In 1958 there were 1,043 cases of typhoid in the United States, or 7 cases per million people. Deaths from this disease were naturally much lower. The incidence on this basis, therefore, would correspond to a ratio of about 6 typhoid bacteria per million *E. coli*. Therefore, 1 ml of the sewage containing 1 million coliforms might contain as many as 6 typhoid bacteria (on the basis of *E. coli* in the sewage, this ratio would be even lower, but for the purposes here the ratio of 6 is used). When the coliforms in the effluent are reduced to 1 per ml by chlorination, it is safe to assume that typhoid organisms will be reduced by the same ratio. Therefore, one typhoid bacterium would be left in 6,000 l of the effluent.

That such a level of typhoid bacteria would not represent a public health menace, even before dilution by the receiving body of water and irrespective of the uses of the water, is apparent. Assuming a dilution factor of 10:1, one typhoid organism would be present in 60,000 l of the water. It is also true that there is a well-established death rate of these organisms with time under stream-flow conditions. For bathing purposes, one out of 60,000 people bathing would have to take in as much as 1 l of water to be likely to swallow that single typhoid bacterium. From the standpoint of potable supply this hypothetical 1 typhoid organism per 60,000 l of water would be further subjected to coagulation, sedimentation, filtration, and chlorination, which reduces its chance of survival, at least, by 99.99 per cent; the chances of a single typhoid bacterium in 60,000 l of water escaping unharmed after such a treatment becomes extremely remote (one in 6 million l of water).

A second and a simpler approach to this problem is as follows: The level of coliform organisms generally allowed for bathing areas is 2,400 per 100 ml of water. An effluent with 1 positive confirmed coliform out of 5 1-ml inoculations would correspond to 20 coliforms

per 100 ml. Even before dilution, sewage effluent is expected to have a lower coliform count than that allowed for bathing beaches. The allowable coliform density in potable water is accepted to be 1 per 100 ml, indicating that the sewage effluent, even before dilution, should have only 20 times as many coliforms as drinking water. From the standpoint of raw water supply, Streeter (12) established that a water containing 5,000 *E. coli* per 100 ml can be treated by ordinary coagulation, sedimentation, filtration, and chlorination as practiced in water treatment plants, and produce a finished water which satisfies the coliform standard for potable water (1 per 100 ml). Again, the effluent from a sewage treatment plant is expected to have a lower coliform count even before dilution and self-purification than the established coliform density for raw water supply.

The objectives of disinfection and regulations for setting the coliform density in sewage effluents need to be established from a proper perspective. The indirectness of control of disinfection by using the coliform numbers rather than the actual pathogenic bacteria, which represent the real health hazard; the lack of validity of coliform organisms as true indications of fecal pollution; and, finally, the common usage of chlorine residuals rather than coliforms as a measure of attainment of the objective of disinfection, and lack of correlation between residuals and coliforms, makes adherence to a rigid coliform standard in the effluent untenable. More judgment and less adherence to "sacred cows" is needed.

Two courses are open: One is to raise the sights of disinfection of effluents so that the virus of infectious hepatitis is destroyed, because in the United States this is the only disease besides typhoid and dysentery that might be attributed to the water supply. This will require chlorination to higher residual levels than those commonly practiced. The question might be raised as to whether this objective might not be more effectively realized at the water treatment plant. It is not known whether, with the present practice of chlorination, discharge of effluent containing the virus constitutes a health menace to bathing beaches. The present practice of chlorination does not destroy viruses, so the situation in regard to health hazard from virus infection in bathing areas could remain as it is at present.

The second course is to lower the sights in respect to effluent chlorination, leaving the destruction of the viruses to water plants. Under such conditions, the hazard from enteric pathogenic bacteria, such as typhoid and dysentery, remaining in the effluent has been shown earlier in this paper to be negligible, even if a somewhat more lenient standard than the absence of confirmed coliforms in more than 1 ml out of 5-ml portions is adopted. It does not seem reasonable to set up rigid coliform standards, and at the same time to permit the control of chlorination on the basis of chlorine residuals, which do not necessarily produce the desired coliform numbers in the effluent.

It would be more logical to control disinfection primarily by the coliform test in order to insure compliance with the standard as was shown to be the case in the two plants discussed earlier, where this practice is followed and where operations are carefully checked. Chlorine residuals can then be made as spot checks. In "Standard Methods" (2), chlorine requirement is defined on this basis, namely as "the amount of chlorine which must be added to sewage to produce a chlorine residual of such strength that after a definite contact time the effluent will show the desired coliform density." Although it is not stated, it is implied that chlorine residual is only a collateral and secondary test to the ul-

timate object to be achieved; namely, the maintenance of certain coliform numbers not in excess of the standard, whatever that standard may be. The foibles of the methods of residual chlorine tests are beyond the scope of this paper, but are well recognized, especially in the case of certain industrial wastes.

Summary and Conclusions

Coliform data from eight waste treatment plants were examined in regard to accomplishment of disinfection by chlorination. Accomplishment was governed by compliance with two coliform standards of 20 and 100/100 ml. Compliance was found to be independent of chlorine residual, and both coliform standards were met in the absence of chlorine and under conditions of chlorine residuals ranging from 0.1 to 5.0 mg/l. Per cent compliance with either coliform standard could not have been predicted, therefore, on the basis of a specific chlorine residual. Similarly, adequate control of disinfection cannot be based on chlorine residual alone. To assure adequate control and accomplishment, coliform bacteria, as well as chlorine residual, must be determined. Compliance was not affected by type of waste treatment, as the data showed that both coliform standards were met in primary and secondary effluents under a wide range of chlorine residuals. No significant preference for compliance, therefore, can be attached to either type of treatment. Higher per cent compliances were observed with contact times of 30 and 33 min than with contact times of 3, 10, and 20 min.

The objectives of sewage disinfection by chlorination have been discussed. It has been pointed out that chlorination of effluents as presently practiced destroys only some of the pathogenic organisms (*Salmonella* and *Shigella*) that may be present, leaving the viruses, mycobacteria, and parasitic worms unaffected. Higher chlorine dosages and residuals must be maintained in order to destroy them. To destroy the *Salmonella* and *Shigella*, however, does not require disinfection to reduce the coliforms, which are used as indicator organisms, to a level not in excess of one coliform in 5-ml inoculations. Disinfection to a level of one coliform in five 1-ml. inoculations is not required to reduce the *Salmonella* and *Shigella* for safeguarding of public health.

Acknowledgment

The authors wish to express their appreciation to the following people and organizations who supplied the data for this paper: T. R. Glenn, Jr., Interstate Sanitation Commission, New York, N. Y.; C. A. Lydecker and M. C. Rand, Middlesex County Sewerage Authority, Sayreville, N. J.; and H. R. Zablatzky, Bergen County Sewage Authority, Hackensack, N. J.

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MEETINGS OF INTEREST

Sept. 21–27	**Illinois Association of Sanitary Districts,** Hilton Inn, North Aurora, Ill. Raymond E. Anderson, North Shore Sanitary District, Waukegan, Ill.
Sept. 24–27	**American Institute of Chemical Engineers,** 45th Annual Meeting, Lake Placid Club, Lake Placid, N. Y.
Sept. 24–27	**American Public Works Congress and Equipment Show,** Municipal Auditorium, Minneapolis, Minn. American Public Works Association, 1313 East 60th St., Chicago 37, Ill.
Oct. 2–6	**International Congress on Control of Water Pollution,** Swiss Industries Fair, Basel, Switzerland. Dr. E. M. Bammatter, PRO AQUA Ltd., 61 Clarastrasse, Basel, Switzerland.
Oct. 10–12	**National Conference on Standards,** American Standards Association, Rice Hotel, Houston, Tex.
Oct. 16–20	**American Society of Civil Engineers,** Annual Convention, Hotel Statler, New York. W. W. Wisely, ASCE, 33 West 39th St., New York 18.
Oct. 16–20	**National Safety Council Annual Meeting,** Chicago, Ill. National Safety Council, 425 North Michigan Ave., Chicago 11, Ill.
Oct. 19–21	**National Society of Professional Engineers,** Hotel Roanoke, Roanoke, Va. NSPE, 2029 K St., N. W., Washington 6, D. C.
Oct. 23–28	**First Inter-American Congress of Chemical Engineering,** San Juan, P. R. Secretary, Institute of Chemical Engineers of Puerto Rico, Box 47, Rio Piedras Sta., P. R.
Oct. 31–Nov. 3	**Second Effluent and Water Treatment Exhibit and Convention,** Seymour Hall, London, England. Thunderbird Enterprises Ltd., 140 Cromwell Rd., London S.W. 7.
Nov. 4	**Pittsburgh Sanitary Engineering Conference,** Graduate School of Public Health, University of Pittsburgh, Pittsburgh, Pa. Dr. Eugene Weisberg, 1626 Forbes Ave., Pittsburgh 29, Pa.
Nov. 13–17	**American Public Works Association,** Cobo Hall, Detroit, Mich. APHA, 1790 Broadway, New York 19.
Nov. 26–Dec. 1	**American Society of Mechanical Engineers,** Winter Annual Meeting, Statler Hilton Hotel, New York. ASME, 345 East 47th St., New York 17.

INDUSTRIAL VIEWPOINT OF SEWER SERVICE CHARGES

J. F. Byrd

It should be considered axiomatic in the field of sanitary engineering and waste treatment that every effort must be made to achieve a desired level of pollution abatement at minimum cost to the community in general. In most communities this total cost can be defined as the expenditure by both industry and the municipality regardless of whether the treatment is carried out in the municipal sewage treatment plant, industrial treatment plant, or a combination of both. Therefore, it is the duty and objective of both the industry and the municipality to determine that combination of facilities which will give the required degree of treatment for the least total cost. To properly achieve this desirable aim of obtaining the lowest over-all cost to the community as a whole, it is absolutely imperative that the sewer service charges levied by the municipality realistically reflect the actual costs of treating the wastes.

For example, a properly derived sewer charge is an incentive to industry to review its various wastes from the standpoint of costs. Some of the industrial wastes with high concentrations of BOD or suspended solids may be more cheaply handled by the industry through such methods as incineration or hauling to a dump, than by discharging the concentrated wastes to the sewer for treatment at the sewage treatment plant. In the latter case, the concentrated wastes become dilute again and the sewage treatment plant must then reconcentrate the wastes in the primary settling tanks for digestion. A realistic sewer service charge will point the way for the industry to take the cheaper alternate, namely to handle the waste itself rather than pay the city to do it. Other wastes may be more easily and cheaply treated by the municipality in their sewage treatment plant than by the industry. In any event, a realistic, fair surcharge points to the best combination of facilities to achieve treatment at minimum cost for all concerned.

At Procter and Gamble perhaps 80 to 90 per cent of wastes are more economically treated by the municipal sewage treatment plant. The remaining wastes are treated by the company either because it is cheaper to do so or because the wastes might have a deleterious effect on the sewage treatment plant and its processes.

Determination of Charges

Generally, methods of arriving at a figure on sewer surcharges range from the very simple to the highly complex. The simplest involves some inequities. The more complex methods eliminate some of these inequities at the sacrifice of simplicity and ease of administration. Therefore, there is no ideal method. In practice a compromise is reached where a little of each is sacri-

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The paper was presented at the 33rd Annual Meeting of the Water Pollution Control Federation in Philadelphia, Pa., Oct. 2–6, 1960.

Editor's note: Mr. Byrd's paper was given at the meeting as a discussion of Kenneth V. Hill's paper (THIS JOURNAL, **33**, *2, 198 (Feb. 1961)*).

ficed. The simplest approach as Mr. Hill pointed out (1) is the quantity method. The total dollars for debt service and costs of operation of the sewage treatment plant is divided by the total gallons of waste handled to obtain a service charge in terms of cost per 1,000 gal based on volume alone. In areas having no industries, the wastes are generally uniform in composition so this approach is satisfactory. In highly industrialized areas, however, the user with dilute wastes subsidizes the user with wastes of high BOD and SS contents. This is certainly not a fair or equitable method of obtaining revenues.

The quality-quantity (Q-Q) method, while not as simple, considers the other two parameters, BOD and suspended solids, which are involved in both the design and operation of a treatment plant. The total cost of waste treatment, i.e., the service charge, is apportioned to BOD and suspended solids as well as volume since all three are factors in both the first cost as well as operating cost of a sewage treatment plant. It would appear then that basically this quality-quantity method of financing is the ideal way of calculating the charges. However, if one digs beneath the surface of this approach, there are certain inequities involving perhaps a philosophical discussion rather than a technical or financial approach. Mr. Hill has pointed out that a sewage treatment plant is designed for both future capacity as well as infiltration from all properties. Therefore, the treatment plant benefits both users and properties. Yet, in the quantity-quality method of sewer service charges the actual user alone pays the entire bill.

This fact has led to the joint council method described by Mr. Hill in which users and other property owners alike pay charges proportional to the benefits received. The joint council method is, in reality, an extension of the quantity-quality method. Part of the revenues are obtained by charges based on BOD, SS, and volume of wastes discharged to the sewer and another portion by property taxes on all properties. This method is certainly the most equitable method developed to date. It is also the most complex of the system of sewer charges to administer although it does not appear to be unduly complex. As a matter of history the joint council method was developed by a Committee, consisting of representatives from such groups as the American Society of Civil Engineers, the Water Pollution Control Federation (then Federation of Sewage Works Associations), and the American Public Works Association.

In most areas where Procter and Gamble operates factories, various modifications of the quality-quantity methods are utilized. In several instances a simplified approach is made toward the joint council method by the expedient of indirect discounts given to the users. While not the ideal method from the standpoint of equities, the Q-Q method is generally quite fair and provides a straightforward, simple, and sound basis for a sewer charge. However, it is believed that industry would like to see a greater trend toward the joint council method.

At the present, pollution abatement is an accepted fact of life and rightfully so. Industry considers waste treatment as a natural and legitimate cost of doing business. Just as steam, electric power, and water are normal manufacturing expenses, so are sewer service charges.

Summary

To summarize, the important features of any sewer service charge can be listed as follows:

1. The user should be willing to pay its fair share of the costs of treatment.

2. The municipality must establish an equitable system of sewer charges so that all parties concerned, the individual tax payer and the industries,

can benefit from the economic advantages of joint treatment. Consideration should be given to the concept of charging all properties who may benefit from the sewer system as well as the users.

3. The sewer tax should apply to all users; specially negotiated rates for some classes of users merely penalize the others.

Combined treatment of industrial wastes and domestic sewage in a municipal sewage treatment plant is generally the most economical approach to waste abatement. To be a success each party must honor its obligations to the other. The industry should pretreat wastes as necessary to remove any substances which may have an adverse effect on the equipment or process of a sewage treatment plant. The municipality on the other hand must be willing to treat all wastes which can be handled satisfactorily in its sewage treatment plant in exchange for a fair fee which actually reflects the costs of treating the wastes.

Experience in this company at several locations in the U. S. has shown that all city authorities have discharged their obligations and responsibilities in the field of sewer charges and sewer taxes in a most commendable manner.

Acknowledgments

Credit is also due to Mr. R. C. Peterson and Mr. V. E. Gex of Procter and Gamble Company for their work with municipal authorities in the field of joint treatment of domestic and industrial wastes.

Reference

1. Hill, K. V., "Fair Sewer Service Charges for Industrial Wastes." THIS JOURNAL, **33**, 2, 198 (Feb. 1961).

MONTHLY CONTRACT AWARDS—SEWAGE TREATMENT WORKS AND COLLECTING SEWERS AS REPORTED BY THE PUBLIC HEALTH SERVICE (MILLIONS OF DOLLARS)

Month (1961)	Treatment		Sewers		Total	
	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative
Jan.	24.4	24.4	22.4	22.4	46.8	46.8
Feb.	33.5	57.9	22.3	44.7	55.9	102.7
Mar.	47.1	105.0	30.1	74.8	77.2	179.9
Apr.	30.6	135.6	33.5	108.3	64.1	244.0
May	50.9	186.5	39.3	147.6	90.2	334.2
June	37.9	224.4	42.6	190.2	80.5	414.7

SLUDGE REAERATION IN THE ACTIVATED SLUDGE PROCESS–A SURVEY

T. R. Haseltine

Sludge reaeration is defined as "the continuous aeration of sludge after its initial aeration in the activated sludge process" (1). As regards the activated sludge process, the wording of the "Ten States Standards" (2) and the Pennsylvania Sewerage Manual (3) are identical. They state that "consideration should be given to reaeration of return sludge if conditions are anticipated that favor its use," but do not indicate what those considerations or conditions may be. Opinion differs greatly among the various state regulatory agencies. For example, the Illinois State Health Department is of the opinion that the use of sludge reaeration makes possible a material reduction in total aeration tank volume required (4). As a result Illinois has at least 17 plants that utilize sludge reaeration. Some other states do not look with favor on any reduction in aeration tank volume because of sludge reaeration. In the past, both Pennsylvania and New Jersey frequently took such a stand, but recently Pennsylvania has relaxed its view somewhat.

It has been established that the efficiency of the activated sludge process is related directly to the weight of total or volatile sludge solids carried in the aeration tanks and inversely to the BOD load applied to those tanks. In 1955 a design procedure was proposed that took both of these factors into consideration (5). The procedure was claimed to be as applicable to plants utilizing sludge reaeration as to those that did not. However, that claim was not supported by actual operating data on sludge reaeration plants, despite the fact that an extensive tabulation of operating data for conventional plants was presented.

There has been a paucity of published operating data on sludge reaeration. However, data were made available from the files of the Illinois State Health Department (4). In a further effort to augment available data, questionnaires were addressed to 27 municipalities in various parts of the country that were known to practice sludge reaeration. Sixteen replies were received. In some instances the respondents could not furnish sufficiently complete data to be of much value, but in other instances the replies were extremely detailed and complete.

Historical

The first full-scale activated sludge plants constructed in the United States were the North and South Side plants at Houston, Tex. (6). They both utilized sludge reaeration and went into operation in 1917. In 1923 (7) it was reported that, "the use of sludge reaeration would probably effect a saving of 20 per cent in tank volume, permit use of a shorter (mixed liquor) aeration period, and effect a slight saving in air consumption." Sludge reaeration was provided for in the design of the (Chicago) DesPlaines plant that went into operation that year. Other early plants that had facilities for reaerating the return sludge were Pasadena, Calif. (1924); Mamaroneck,

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The paper was presented at the Annual Meeting of the Pennsylvania Water Pollution Control Assn. in University Park, Pa., Aug. 10 12, 1960.

N. Y. (1925); Pomona, Calif. (1926); and Waco, Tex. (1927). The approximate percentages of the total aeration tank volume allotted to sludge reaeration in these early designs were as follows (6): Houston (N.S.), 33; DesPlaines, 10; Pasadena, 10; Mamaroneck, 4; Pomona, 3; and Waco, 6.

Presumably, the original design of the Houston South Side plant was also predicated on the use of 33 per cent of the aeration tank volume for sludge reaeration. However, the design of both plants must have provided for considerable flexibility in this respect because Garrett (8) advises that at the North Side plant during 1929–30 only 5 to 6 per cent of the aeration tank volume was used for sludge reaeration. In contrast, he gives figures for 9 months' operation at the South Side plant during 1931 which indicate that from 20 to 50 per cent of the aerator capacity was used for sludge reaeration. The 9-month average was 32 per cent. He advises that although sludge reaeration has since been abandoned at the North Side plant, it is still in use at the South Side plant and also at Houston's newer District 17 plant.

During 1935–36 activated sludge plants incorporating sludge reaeration were constructed at San Antonio, Tex. (9) and Topeka, Kans. (10). The San Antonio design provided for reaeration in 7.5 per cent of the total aeration tank volume; the corresponding figure for Topeka was 14.2 per cent. Reaeration may have been included in several other early designs. However, in 1938 Mohlman (11) stated:

> Reaeration of sludge is another phase of plant design that has developed differently in various countries. In England reaeration is common practice, but no convincing evidence has ever been presented to show that reaeration is either more effective or more economical, over-all than an equal tank capacity devoted to straight aeration. Some observers claim that reaeration is economical because only one-fourth to one-fifth of the volume of sewage is reaerated as sludge but from the biological viewpoint, and the question of activity of sludge, there is no evidence that reaeration results in intensified sludge activity. It is doubtful whether dissolved oxygen can be present in the concentrated sludge present in reaeration tanks. Possibly the provision of reaeration tanks may help a difficult situation where industrial wastes are variable and toxic, in providing a reservoir of sludge that is buffered against the poisonous effect of a brief influx of toxic waste. This seems to be the most valid reason for the use of reaeration in activated sludge practice. Neither in the DesPlaines River Plant nor several comparative large-scale tests at the North Side Plant, was any advantage shown by reaeration of sludge. Tests at Berlin also showed similar results.

In 1941 the APHA Committee on Sewage Disposal (12) concluded that separate sludge reaeration was of little value. However, at or about that same time, Gould (13) (14), Hatfield (15), Kraus (16) (17), and others were developing new flow diagrams or process modifications that were dependent on sludge reaeration. Such development has continued and many of the developers have coined new names for their modifications of the old sludge reaeration practice.

Methods of Application

Figure 1 shows the flow diagram utilized in the older (prior to 1938) sludge reaeration plants previously mentioned. It is also a flow diagram for some of the present sludge reaeration processes such as "Biosorption," "contact stabilization," "Ridgewood biological coagulation process," "extended reaeration," etc. None of these processes is patented. The principal difference between the old and new processes is in the percentage of total aeration tank volume utilized for sludge reaeration. As previously noted, the old designs generally allotted only 10 per cent or less of that volume to sludge reaeration. In contrast, Zablatsky *et al.* (18) utilized 50 to 67 per cent of the tank volume for reaeration in the contact stabilization process, and Hood and Spohr (19) used 80 to 86 per cent in their pilot studies of the Ridgewood biological co-

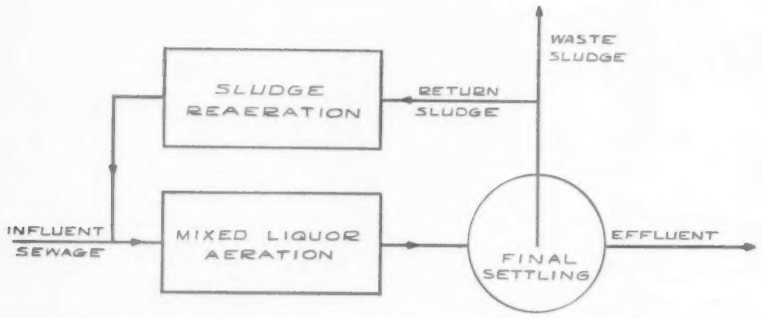

FIGURE 1.—Flow diagram for "extended reaeration" as practiced at Indianapolis.

agulation process. Biosorption is a registered trademark. It is claimed that the sludge reaeration (termed sludge stabilization) volume constitutes about 68 to 70 per cent of the total aeration volume. Extended reaeration is the term used by Bender (20) at Indianapolis. There the reaeration volume ranges from 25 to 50 per cent of the total aeration volume. Because this term seems to most clearly indicate the difference between the present and the historical use of the Figure 1 flow diagram, it has been used in this paper to designate all of the foregoing modern day processes.

The "Hatfield Process" (15), which has been in use at Decatur, Ill., since 1942, utilizes a flow diagram similar to that shown in Figure 1 except that either supernatant liquor or digesting sludge from the anaerobic digesters is introduced directly into the sludge reaeration tank, either continuously or intermittently, in such quantities as the operator finds advisable. Although only one-third of the aeration tank volume is used for sludge reaeration at Decatur, Hatfield (21) believes that better results would be obtained if it were possible to utilize about one-half of that volume for reaeration. This process is not patented.

In all of the foregoing "processes" all return sludge is reaerated before joining the sewage to flow through the mixed liquor aeration tank. Figure 2 is a flow diagram for the "Kraus inter-

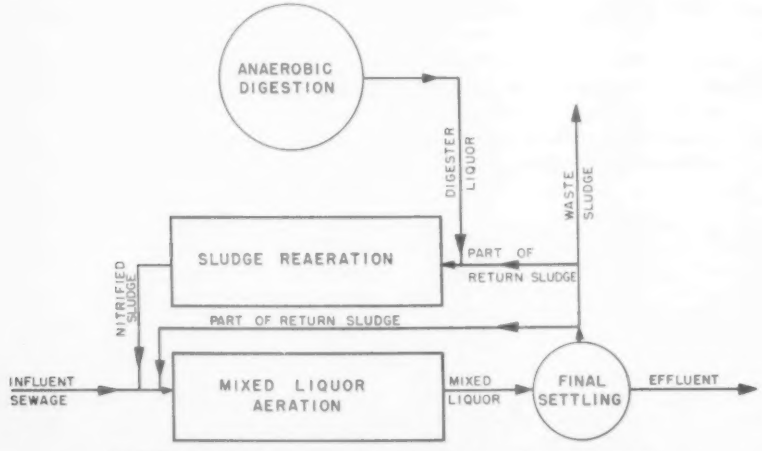

FIGURE 2.—Flow diagram for Kraus interchange process.

change process," developed at Peoria, Ill. (16) (17) (22). In this process the return sludge flow is split, with the major portion going directly to the mixed liquor aeration tank as in the conventional or normal activated sludge plant and a minor portion, generally 10 to 20 per cent of the total return flow, going to the sludge reaeration tank. As in the Hatfield process, digester supernatant or digesting anaerobic sludge is introduced into the reaeration tank, generally at a low but continuous rate. The reaeration tank is termed a "nitrification" tank and a reaeration or nitrification period of 24 hr is considered desirable although shorter periods have been used. This process is patented.

Figure 3 is a flow diagram for the "Gould Step Aeration Process" (13) (14) on which patents expired in December 1960. In this process, return sludge from the final clarifiers is delivered to the head end of the aeration tank, the piping being so arranged that the sewage may be introduced either at that point or at one or more points farther along the aeration tank. If the aeration tank is arranged as indicated in Figure 3, it is obvious that the plant may be operated with no reaeration at all, or with 25, 50, or 75-per cent of the aeration tank volume being utilized for sludge reaeration. In practice, the sewage flow is frequently split and introduced at two, or even three, of the four inlets. When so operated, there obviously is an intermediate zone which cannot be considered as being solely sludge reaeration or solely mixed liquor aeration; therefore neither period can be calculated. Solids concentrations will decrease from bay to bay, being a maximum (that of the return sludge) in the first bay and a minimum (that of the mixed liquor) in the last bay.

Presentation of Data

To facilitate comparison of conventional plants with those practicing

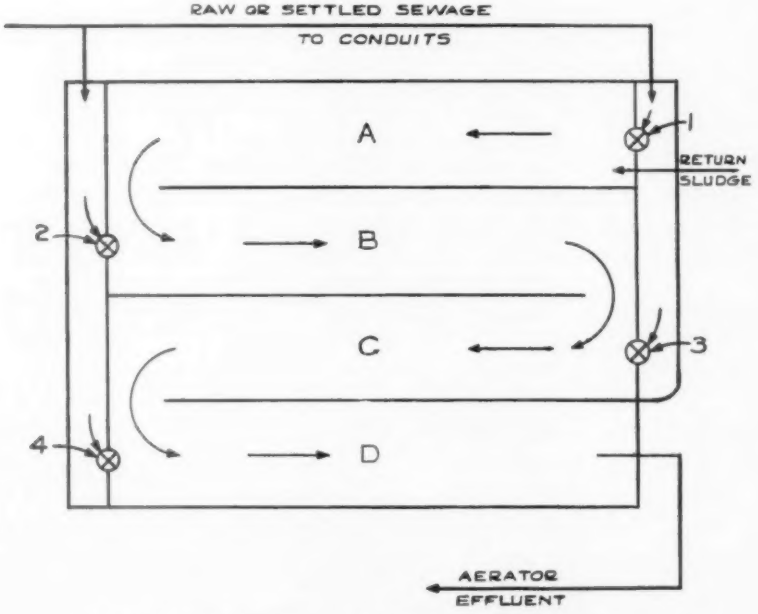

FIGURE 3.—Flow diagram for Gould Step Aeration Process.

TABLE I.—Summary of Aeration Tank Operation at Conventional * Activated Sludge Plants (Ref. 5)

Plant	Time of Record		Sewage to Aerators			Mixed Liquor SS (mg/l)	Return Sludge % of Flow	BOD Applied (lb/day)		Air Used (cu ft)		Mixed Liquor Aer. Period (hr)	Removal (%)	
	(19—) Year	No. of Mo.	Quant. (mgd)	Susp. Sol. (mg/l)	5-Day BOD (mg/l)			Per 1,000 cf Aer. Tank Vol.	Per 100 lb Sol. Under Aer.	Per Gal	Per lb BOD Removed		SS	BOD
Ann Arbor, Mich.	44–46	28	5.0	128	182	1,840	32.0	39.0	34.0	1.05	770	5.3	90.7	89.6
Ann Arbor, Mich.	47	12	6.7	107	169	1,850	30.8	47.1	41.1	0.92	703	4.1	89.0	92.3
Baltimore, Md.	45	12	10.6	92	217	940	21.5	28.8	49.9	1.24	728	9.3	91.3	93.6
Chicago, Ill., S. W.	46	12	288.0	—	129	1,930	47.9	21.0	17.7	0.86	876	5.9	—	91.5
Chicago, Ill., S. W.	51–52	24	794.0	105	97	2,330	38.5	32.0	21.8	0.68	905	3.3	86.0	92.0
Chicago, Ill., N. Side	46	12	197.5	—	97	2,400	24.0	22.1	14.8	0.49	645	5.3	—	93.8
Chicago, Ill., N. Side	46–50	60	213.0	88	77	2,000	22.7	19.0	15.4	0.48	800	4.9	88.5	92.5
Chicago, Ill., Calumet	46	12	71.8	—	94	2,190	25.9	21.6	15.7	0.48	677	5.2	—	90.4
Chicago, Ill., Calumet	46–50	60	77.0	105	87	2,230	24.4	19.0	15.4	0.48	740	4.9	87.0	87.5
Cleveland, Ohio, East	40–45	72	86.9	146	91.5	2,180	24.9	17.4	12.5	1.06	1,600	6.2	90.8	86.9
Ft. Wayne, Ind.	41–45	60	14.9	151	161	2,420	30.5	23.7	15.8	0.95	773	7.7	89.1	91.0
Gary, Ind.	41–45	60	19.0	101	77	1,330	33.2	19.4	23.5	0.47	796	4.4	92.9	89.6
Hagerstown, Md.	43–46	28	3.87	286	254	1,810	31.5	44.1	39.0	0.92	500	6.7	95.5	86.8
Hammond, Ind.	42–46	60	20.2	152	135	2,200	51.9	19.5	14.4	0.66	655	7.2	88.8	91.5
Indianapolis, Ind.	42	12	17.8	215	182	2,400	27.2	26.1	17.3	1.45	847	8.3	96.7	95.0
Indianapolis, Ind.	43	12	7.98	224	181	2,600	70.0	27.0	12.5	1.68	1,060	7.9	94.2	92.2
Indianapolis, Ind.	44	12	11.3	234	193	2,800	83.3	16.5	10.1	1.52	1,095	8.9	97.9	94.8
Jackson, Mich.	42–46	60	8.04	144	118	2,800	15.5	26.4	14.9	0.65	690	5.8	88.5	94.9
Madison, Wis.	47	12	7.60	—	157	1,090	51.6	26.4	38.8	1.23	690	6.0	—	77.1
Marion, Ind.	42–45	76	3.92	117	134	2,630	30.8	35.4	21.6	0.89	886	4.3	89.2	89.7
Marshalltown, Iowa	43–46	36	3.35	130	177	2,500	31.3	28.6	18.3	1.45	1,245	7.0	62.3	79.2
Milwaukee, Wis., West	45	12	65.4	315	332	3,000	24.9	47.0	25.2	1.90	725	8.5	93.6	94.6
Milwaukee, Wis., East	45	12	56.0	315	332	3,000	21.5	52.0	30.3	1.26	481	7.9	95.2	94.8
Omaha, Nebr.	46	12	2.54	149	128	1,720	60.4	15.8	14.7	1.04	1,210	7.6	79.9	80.5
Pontiac, Mich.	46	12	4.8	73	125	1,200	20.8	32.5	43.5	0.83	886	4.8	86.3	90.0
Richmond, Ind.	42–46	60	5.45	92	113	1,680	28.5	20.6	19.8	0.39	435	6.4	82.6	94.7
Springfield, Ill.	42	12	9.2	81	74	1,580	38.1	15.6	15.9	0.64	1,120	5.5	90.2	89.3
Springfield, Ill.	37–41	60	7.8	120	132	1,683	27.6	23.5	22.6	0.70	710	6.6	90.9	90.2
Syracuse, N. Y.	47	12	4.31	—	236	2,220	26.2	47.8	34.6	1.23	1,410	6.0	—	86.4
Two Rivers, Wis.	46	12	0.98	86	114	1,500	48.0	13.7	14.6	—	—	8.4	80.3	90.9

* No separate sludge reaeration.

TABLE II.—Summary of Aeration Tank Operation at Activated Sludge Plants Utilizing Sludge Reaeration

Plant	Time of Record		Sewage to Aerators			Mixed Liquor to Clarifiers		Return Sludge		BOD Applied (lb/day)		Air Used (cf)		Aeration Period (hr)		Removal (%)		NO_3-N in Eff. (mg/l)	Ref.
	(19—) Year	No. of Mo.	Quant. (mgd)	SS (mg/l)	5-Day BOD (mg/l)	SS (mg/l)	Sludge Density Index	Solids (%)	% of Sewage Flow	Per 1,000 cf Aer. Tank Vol.	Per 100 lb Sol. Under Aer.	Per Gal	Per lb BOD Removed	Mixed Liquor	Sludge Reaeration	SS	BOD		
(a) Historical Plants																			
Houston, Tex., N. Side	29	12	10.2	298	208	2,500	0.79	0.74	30.0	38.0	22.2	1.98	1,350	6.00	1.40	77.5	85.1	5.8	8
Houston, Tex., N. Side	30	12	11.4	246	193	2,390	0.49	0.71	35.1	38.8	23.3	1.81	1,120	5.25	1.23	60.8	76.7	4.2	8
Houston, Tex., S. Side	31	9	4.47	235	178	1,820	1.05	0.37	104.	45.0	30.1	2.05	1,760	2.00	1.79	77.5	78.5	2.8	8
Topeka, Kans.	37–38	11	5.6	106	176	1,250	0.45	0.69	30.9	29.3	29.7	1.32	1,050	5.9	4.2	78.3	85.7	—	10
(b) Extended Reaeration																			
Austin, Tex., A	55	12	7.70	226	307	1,900	0.87	0.69	41.3	158	41.6	1.59	675	0.42	5.70	92.1	93.4	—	9
Austin, Tex., A & B	56	12	11.7	229	292	2,300	0.69	0.61	62.9	104	31.4	1.71	825	0.55	5.35	89.7	92.4	0.41	35
Austin, Tex., A & B	57	12	14.4	198	241	1,720	1.04	0.54	54.1	113	38.8	1.43	817	0.52	5.25	88.0	90.0	0.61	35
Austin, Tex., A & B	58	12	15.7	188	197	1,820	1.03	0.65	44.4	105	30.2	1.40	926	0.55	5.53	88.4	89.4	0.70	35
Austin, Tex, A. & B	59	9	16.8	190	216	1,800	0.87	0.66	41.1	120	34.4	1.29	789	0.50	5.06	88.4	87.5	0.57	35
Bergen Co., N. J.	56	3	—	—	—	—	—	—	—	110	—	—	990	0.67	2.28	—	84.6	—	18
Bergen Co., N. J.	56–57	21	—	—	—	—	—	—	—	42.2	—	—	1,280	1.35	4.32	—	88.7	—	18
Indianapolis, Ind., B	58–59	7	14.7	149	133	1,850	1.01	0.44	75.1	34.5	18.7	1.32	1,430	2.12	3.93	88.6	88.0	1.8	20
Indianapolis, Ind., C	58–59	7	13.5	128	141	1,980	0.90	0.42	82.4	38.1	27.2	1.06	1,010	2.18	1.60	85.1	88.6	1.4	20
Indianapolis, Ind., D	58	8	22.1	108	148	2,020	1.30	0.46	50.6	49.8	23.1	0.99	955	1.88	4.35	82.4	84.5	2.7	20
Salem, Ill.	58–59	13	0.75	96	166	5,090	1.45	1.00	104	46.5	9.0	1.34	1,000	0.65	2.88	94.6	96.5	—	4
(c) Hatfield Process																			
Decatur, Ill.	54	12	4.96	107	190	2,520	1.49	1.36	18.7	46.4	12.9	1.09	817	3.49	11.3	46.1	84.4	—	21
Decatur, Ill.	55	12	5.24	95	166	2,410	1.82	1.51	17.6	43.5	11.0	0.98	878	3.26	10.9	41.1	80.1	—	21
Decatur, Ill.	56	11	5.48	102	187	1,930	1.43	1.44	13.4	49.9	13.2	0.99	779	3.31	14.4	27.5	81.8	—	21
Decatur, Ill.	57	11	6.16	108	141	2,480	1.76	1.87	13.8	42.5	8.7	0.73	733	2.93	13.5	60.2	84.9	1.7	21
Decatur, Ill.	58	11	5.73	120	169	2,750	—	1.67	18.9	46.3	10.6	0.87	700	3.08	9.76	77.8	88.5	—	21
(d) Kraus Process																			
Belleville, Ill.	56	8	3.15	155	184	3,500	1.47	0.97	68.1	32.2	10.3	2.19	1,540	4.33	15.9*	93.1	92.9	—	4, 25
Belleville, Ill.	57	12	4.36	—	197	3,380	1.05	1.07	54.7	38.2	13.2	1.70	1,140	4.02	17.5*	—	91.5	—	4
Belleville, Ill.	58	6	4.90	—	194	3,320	1.49	1.19	48.9	41.6	14.2	1.77	1,260	3.88	9.35*	—	86.9	—	4
Durham, N. C.†	57	12	5.31	149	194	1,670	0.85	—	81.7	27.7	20.6	1.60	1,330	5.31	—	69.1	73.7	—	26
Durham, N. C.†	58	12	5.00	141	195	2,260	0.99	—	74.7	25.4	10.8	1.97	1,360	5.79	—	68.8	88.7	—	26
Durham, N. C.†	59	12	5.72	179	196	2,270	1.32	—	66.7	30.5	10.0	1.95	1,330	5.25	—	84.8	89.8	—	26
Kewanee, Ill.	58–59	6	1.48	—	127	2,640	1.79	0.84	—	72.5	26.5	—	—	—	—	—	84.2	—	4
Peoria, Ill.	56	12	19.1	—	200	4,400	2.22	1.20	52.3	82.0	19.7	1.20	850	1.20	24.0*	—	82.5	—	36
Peoria, Ill.	59	12	18.7	192	219	4,200	1.92	1.14	46.0	90.4	15.8	1.57	1,000	1.26	23.4*	—	85.4	—	36

* Period applies to only part of return sludge, balance receives no separate reaeration.
† Durham not operated as a true Kraus plant, see text.
‡ Periods indeterminate in step aeration plants.

TABLE II.—*Continued*

Plant	Time of Record		Sewage to Aerators			Mixed Liquor to Clarifiers		Return Sludge		BOD Applied (lb/day)		Air Used (cf)		Aeration Period (hr)		Removal (%)		NO_3-N in Eff. (mg/l)	Ref.
	(19—) Year	No. of Mo.	Quant. (mgd)	SS (mg/l)	5-Day BOD (mg/l)	SS (mg/l)	Sludge Density Index	Solids (%)	% of Sewage Flow	Per 1,000 cf Aer. Tank Vol.	Per 100 lb Sol. Under Aer.	Per Gal	Per lb BOD Removed	Mixed Liquor	Sludge Reaeration	SS	BOD		
(e) Step Aeration																			
Indianapolis, Ind., B	57-59	11	12.8	92	124	2,120	0.88	0.49	91.9	33.4	18.9	1.13	1,240	†	†	88.0	88.8	2.1	59
Indianapolis, Ind., C	57-59	15	12.4	108	134	1,960	0.93	0.43	77.3	28.5	17.4	1.09	1,090	†	†	86.1	88.8	2.0	59
Indianapolis, Ind., D	57-58	9	19.3	96	139	2,220	1.09	0.55	49.7	40.7	21.5	1.11	1,080	†	†	89.4	87.8	2.8	59
Indianapolis, Ind., D	59	12	34.3	125	131	2,160	0.88	0.59	31.7	45.1	21.5	0.86	911	†	†	85.2	86.3	2.4	59
Indianapolis, Ind., D	57	11	20.7	156	137	2,850	0.99	0.73	49.0	22.7	10.2	0.98	910	†	†	91.0	94.2	0.30	57
Nassau Co., N. Y.	59	12	110.0	76	71	7,30	0.99	0.29	24.9	35.8	19.1	0.47	910	†	†	80.5	83.8	—	38
N. Y. City, Hunts Pt.	59	12	92.0	91	10	640	1.10	0.25	35.0	29.8	41.6	0.74	933	†	†	89.0	92.2	—	38

sludge reaeration, it is necessary to have operating data on both. The most extensive collection of such data for conventional plants was published in 1955 (5). Those data are repeated herein as Table I.

Table II summarizes all available data on aeration tank operations for sludge reaeration plants in much the same manner as those for conventional plants are summarized in Table I. However, it contains some additional data on sludge indexes and nitrification. Table III summarizes final clarifier operations at those sludge reaeration plants where such data were obtainable. In all three tables, the data are presented as averages over protracted periods of time; that is, 12 to 76 months in Table I, 3 to 21 months in Table II, and 9 to 15 months in Table III. Because long-term averages do not give a good picture of variations in plant performance, Table IV gives the range in monthly averages at the reaeration plants.

In considering these data it is pertinent to bear in mind the differences in primary treatment utilized at the various plants. At Austin, bar screens and grit chambers provide the only treatment prior to admission of the sewage to the aeration tanks. At all of the other plants listed in Table II the sewage receives primary sedimentation and/or flotation treatment ahead of the activated sludge process. However, at Belleville, Ill., and Durham, N. C., it also receives treatment on roughing filters before entering the aerators. It is possible that these differences materially affect the treatability of the sewage by the activated sludge process. However, no allowance for such differences has been made in Tables I to IV.

In all cases the BOD loadings and removals have been calculated solely from the volume and BOD of the sewage entering the aeration tanks. If that sewage received supernatant liquor from digesters, thickeners, elu-

TABLE III.—Summary of Final Clarifier Operation at Activated Sludge Plants Utilizing Sludge Reaeration

Plant	Final Effl. Susp. Solids (mg/l)	Final Clarifier Loading on Basis of Sewage Flow Alone			Ratio of Return Sl. Sol. to Sludge Density Index	Return Sludge Flow % Sewage Flow
		Surface Rate (gpd/sq ft)	Weir Rate (gpd/ft)	Detention (hr)		
(*a*) Historical Plants						
Houston, Tex., N. Side	67	975	—	—	0.93	30.0
Houston, Tex., N. Side	97	1,050	—	—	1.45	35.1
Houston, Tex., S. Side	55	1,180	—	—	0.35	104
Topeka, Kans.	23	635	11,900	3.1	0.80	30.9
(*b*) Extended Reaeration						
Austin, Tex., A	18	580	10,900	3.7	0.79	41.3
Austin, Tex., A & B	24	475	9,400	4.5	0.88	62.9
Austin, Tex., A & B	24	584	11,500	3.7	0.52	54.1
Austin, Tex., A & B	22	635	12,600	3.4	0.63	44.4
Austin, Tex., A & B	22	682	13,500	3.1	0.76	41.1
Indianapolis, Ind., B	16	604	6,900	3.5	0.44	75.1
Indianapolis, Ind., C	16	563	6,350	3.8	0.47	82.4
Indianapolis, Ind., D	20	634	10,050	4.0	0.35	50.6
Salem, Ill.	5	—	—	1.3	0.70	104
(*c*) Hatfield Process						
Decatur, Ill.	57	409	32,000	5.2	0.89	18.7
Decatur, Ill.	56	431	33,800	5.0	0.83	17.6
Decatur, Ill.	74	—*	—*	—*	1.01	13.4
Decatur, Ill.	44	508	8,000	4.2	1.06	13.8
Decatur, Ill.	27	472	7,900	4.5	—	18.9
(*d*) Kraus Process						
Belleville, Ill.	13	633	—	5.8	0.66	68.1
Durham, N. C.	46	332	29,200	6.0	—	81.7
Durham, N. C.	44	312	28,400	6.3	—	74.1
Durham, N. C.	28	358	31,400	5.5	—	66.7
Peoria, Ill.	33	900	21,200	2.7	0.59	46.0
(*e*) Step Aeration						
Indianapolis, Ind., B	14	528	6,000	4.4	0.56	91.9
Indianapolis, Ind., C	15	547	5,800	4.1	0.46	77.3
Indianapolis, Ind., D	17	572	8,800	4.2	0.51	49.7
Indianapolis, Ind., D	21	982	15,600	2.5	0.67	31.7
Nassau Co., N. Y.	14	765	9,900	2.9	0.74	49.0
N. Y. City, Hunts Pt.	10	905	152,000	2.4	0.32	24.0
N. Y. City, Wards Is.	15	765	142,000	3.0	0.23	35.0

* Clarifiers altered during 1956 to quintuple length of effluent weirs.

triation tanks, etc., or filtrate from sludge dewatering operations, prior to its sampling then the effect of those in-plant wastes are included in the BOD loadings. However, the loadings reported for the Kraus and Hatfield plants do not include the BOD of the digester sludge or supernatant intro-

TABLE IV.—Variation in Monthly Averages of Operating Data

Item	Historical Plants			Extended Reaeration				Hatfield Proc.	Kraus Process				Step Aeration	
	Houston, Tex., N. Side	Houston, Tex., S. Side	Topeka, Kans.	Austin, Tex.	Bergen Co., N. J.	Indianapolis, Ind.	Salem, Ill.	Decatur, Ill.	Belleville, Ill.	Durham, N. C.[a]	Kewanee, Ill.	Peoria, Ill.	Indianapolis, Ind.	Nassau Co., N. Y.
Months included (no.)	12	9	11	45	24	22	13	57	26	35	6	12	47	11
BOD red. by act. sl. proc. alone (%):														
Median	73.9	80.2	82.8	90.1	89.8	88.0	97.1	84.8	91.6	88.0	85.8	85.8	87.8	91.7
High quartile	85.0	81.8	94.6	92.7	94.0	89.8	97.9	87.8	93.3	91.5	89.1	87.4	89.9	92.7
Low quartile	70.5	76.9	75.4	88.2	82.4	85.9	96.4	79.4	90.2	79.7	78.3	85.0	85.3	91.1
Maximum	87.3	87.0	95.7	94.3	97.0	91.7	98.3	94.2	96.1	93.8	90.1	87.9	93.2	95.5
Minimum	57.9	61.7	70.9	85.2	79.0	85.1	95.6	70.4	79.3	60.8	75.0	78.0	80.7	86.2
NO_3-N in effluent (mg/l):														
Median	4.4	2.3	—	0.6[b]	—	1.9	—	1.2[c]	—	—	—	—	2.0	—
High quartile	5.0	4.3	—	0.8[b]	—	2.6	—	2.4[c]	—	—	—	—	3.3	—
Low quartile	3.1	1.6	—	0.4[b]	—	1.1	—	0.8[c]	—	—	—	—	1.0	—
Maximum	5.9	6.3	—	1.8[b]	—	5.1	—	3.6[c]	—	—	—	—	6.0	—
Minimum	2.5	1.2	—	0.22[b]	—	0.58	—	0.7[c]	—	—	—	—	0.32	—
BOD input to aer. tanks (lb/day/1000 cu ft tank vol):														
Median	38.9	46.1	29.6	111	42.6	37.4	46.2	46.0	35.9	27.2	71.8	89.2	36.0	26.5
High quartile	44.5	52.4	32.7	146	49.7	46.0	58.1	50.3	43.2	32.7	100.5	92.3	45.1	30.9
Low quartile	35.8	36.5	25.0	107	37.0	33.9	36.8	41.1	29.7	24.1	46.7	79.9	27.3	22.3
Maximum	55.0	58.9	39.6	177	113	68.2	65.2	65.4	51.4	39.8	105	107	58.7	47.5
Minimum	24.0	29.2	20.9	80.7	34.3	29.6	21.9	29.2	23.8	17.9	46.0	70.9	13.5	16.2
Mixed liq. aeration period (hr):														
Median	5.19	2.20	5.8	0.50	1.37	2.04	0.76	3.14	4.05	5.40[d]	—	—	—	—
High quartile	5.31	2.46	6.4	0.55	1.48	2.23	0.81	3.46	4.53	5.95[d]	—	—	—	—
Low quartile	5.16	1.42	5.4	0.44	1.03	1.83	0.70	2.98	3.63	5.06[d]	—	—	—	—
Maximum	5.45	2.80	6.9	0.58	1.68	3.12	0.88	4.37	5.04	6.50[d]	—	—	—	—
Minimum	4.97	1.24	5.3	0.37	0.44	1.31	0.60	2.30	2.91	4.35[d]	—	—	—	—
Sludge reaeration period (hr):														
Median	1.28	2.62	4.15	5.30	4.29	2.58	2.73	11.1	14.1[e]	—	—	—	—	—
High quartile	1.29	2.76	4.4	5.70	5.02	4.63	3.16	15.2	19.6[e]	—	—	—	—	—
Low quartile	1.22	1.15	3.9	4.97	3.44	1.69	2.61	9.1	12.2[e]	—	—	—	—	—
Maximum	1.30	5.17	4.9	6.90	5.51	8.40	3.71	19.5	29.4[e]	—	—	—	—	—
Minimum	0.93	1.00	3.9	4.47	2.07	1.51	2.29	8.4	10.0[e]	—	—	—	—	—
Air used (cu ft/lb BOD removed):														
Median	1,570	1,410	1,245	862	1,200	967	985	818	1,350	1,390	—	1,010	1,050	1,040
High quartile	1,760	2,220	1,440	917	1,410	1,180	1,300	951	1,450	1,590	—	1,120	1,400	1,500
Low quartile	1,200	1,400	889	699	1,060	899	845	720	1,070	1,110	—	970	914	875
Maximum	2,560	2,940	1,600	1,210	1,930	1,430	2,520	1,320	2,390	2,180	—	1,280	2,430	2,250
Minimum	879	1,300	453	526	839	735	621	550	965	950	—	885	621	550
BOD input to aer. tanks (lb/day/100 lb sol. under aeration):														
Median	23	36	30	37	—	20	9.7	12	12	11[f]	—	—	19	9.3
High quartile	28	44	38	44	—	24	11	14	14	14[f]	—	—	24	11
Low quartile	21	21	27	34	—	18	7.0	8.9	10	9.6[f]	—	—	14	8.6
Maximum	33	54	39	58	—	28	12	20	20	32[f]	—	—	42	15
Minimum	17	14	18	21	—	17	5.1	5.5	7.7	7.1[f]	—	—	9.1	7.3
Mixed liquor sludge density index:														
Median	0.41	1.05	0.57	1.00	—	1.04	1.43	1.67[g]	1.41	1.15[d]	—	1.89	1.05	2.08
High quartile	0.66	1.35	0.88	1.14	—	1.25	1.67	2.08[g]	1.64	1.35[d]	—	1.92	1.20	2.28
Low quartile	0.34	0.93	0.29	0.86	—	0.92	1.30	1.37[g]	0.94	0.92[d]	—	1.82	0.88	1.85
Maximum	1.41	1.41	1.25	1.54	—	1.82	1.85	3.70[g]	2.27	1.79[d]	—	2.08	2.08	2.44
Minimum	0.29	0.79	0.20	0.69	—	0.68	1.10	0.85[g]	0.60	0.40[d]	—	1.79	0.45	1.76

[a] Durham plant not operated as a true Kraus plant, see text.
[b] Based on 33 months.
[c] Based on 8 months.
[d] Based on 36 months.
[e] Period applies to only part of return sludge; balance receives no separate reaeration.
[f] Based on 34 months.
[g] Based on 42 months.

TABLE IV.—*Continued*

Item	Historical Plants			Extended Reaeration				Hatfield Proc.	Kraus Process				Step Aeration	
	Houston, Tex., N. Side	Houston, Tex., S. Side	Topeka, Kans.	Austin, Tex.	Bergen Co., N. J.	Indianapolis, Ind.	Salem, Ill.	Decatur, Ill.	Belleville, Ill.	Durham, N. C.[a]	Kewanee, Ill.	Peoria, Ill.	Indianapolis, Ind.	Nassau Co., N. Y.
Return sludge solids (%):														
Median	0.61	3.20	0.38	0.62	—	0.44	1.04	1.44	1.05	—	—	—	0.51	0.72
High quartile	0.71	4.39	0.40	0.71	—	0.48	1.10	1.77	1.12	—	—	—	0.60	0.82
Low quartile	0.58	3.04	0.33	0.55	—	0.41	0.90	1.29	0.95	—	—	—	0.47	0.66
Maximum	1.34	6.34	0.44	0.89	—	0.52	1.22	2.51	1.38	—	—	—	0.67	0.85
Minimum	0.54	2.00	0.21	0.40	—	0.31	0.57	0.93	0.88	—	—	—	0.33	0.56
Susp. sol. in mixed liquor to final clarifiers (mg/l):														
Median	2,100	1,700	1,200	1,780	—	1,970	5,330	2,290	3,500	2,220[d]	—	—	2,070	2,900
High quartile	2,750	2,410	1,430	2,010	—	2,220	5,680	2,660	3,600	2,360[d]	—	—	2,390	3,130
Low quartile	2,000	1,510	1,080	1,630	—	1,720	4,700	2,050	3,100	2,060[d]	—	—	1,800	2,800
Maximum	3,800	2,770	1,560	2,460	—	2,400	6,030	4,050	4,400	2,950[d]	—	—	2,870	3,300
Minimum	1,650	1,200	830	1,210	—	1,480	3,920	1,300	2,400	870[d]	—	—	1,480	2,400
Ratio of return sludge sol. to sludge density index:														
Median	1.43	0.30	0.58	0.66	—	0.43	0.74	0.90[e]	0.79	1.46	—	—	0.51	0.73
High quartile	1.73	0.33	1.39	0.75	—	0.47	0.79	1.04[e]	1.02	2.06	—	—	0.64	0.84
Low quartile	0.99	0.28	0.33	0.53	—	0.32	0.62	0.75[e]	0.69	1.05	—	—	0.39	0.65
Maximum	2.02	0.68	2.14	1.15	—	0.57	0.87	1.73[e]	1.55	3.22	—	—	1.40	0.97
Minimum	0.93	0.25	0.19	0.38	—	0.27	0.37	0.50[e]	0.36	0.37	—	—	0.23	0.47

duced directly to the reaeration tanks. In most instances the operators of those plants do not make routine BOD determinations of digester supernatant. Kappe (23) has shown that the BOD of such liquor may vary over wide limits. However, to illustrate the magnitude of this added load, a value of 1,500 mg/l has been assumed for all plants listed in Table V, from which it appears that the actual BOD loading at those plants may have been 4 to 5 per cent higher than indicated in Tables II and IV. If so, the percentage reductions shown in these tables may be about 1 per cent low.

TABLE V.—Effect of BOD Load of Added Digester Liquor

Plant	Year	Digester Liquor to Reaeration (gpd)	Digester Liquor BOD	
			(lb/day)	% of BOD Load Shown in Table II
Belleville, Ill.	1956	15,800	198	4.0
Decatur, Ill.	1958	23,800	298	4.2
Durham, N.C.	1957–59	35,000	437	5.1
Peoria, Ill.	1956	140,000	1,750	5.5

Although the Durham plant has been labeled as a Kraus process plant, there is some doubt concerning the validity of that classification. In most true Kraus plants, there is a continuous flow through the reaeration tank, whereas at Durham the reaeration tank is used simply as a conditioning tank for digester liquor before adding it to the aeration tanks.

Malone (24) reports:

> Practically no return sludge goes into the Kraus tank and only digester liquor from the second-stage digestion tank is added as required. . . . After aeration, about 30,000 gal from the Kraus tank are fed in with the return sludge to the aeration tanks during a period of 2 to 2½ hr during the time of day when the flow begins to increase, beginning about 7:00 A.M. This assumes that the activated sludge is in the best condition of the 24 hr due to the light load during the night and anticipates dilution by the increasing flow into the plant. After this amount is withdrawn from the Kraus tank, it is replaced by digester liquor and aerated until shortly be-

TABLE VI.—Comparison of Long-Period Average Data for Conventional and Sludge Reaeration Plants

Item	Plant Type	Avg	Median	High Quartile	Low Quartile	Max	Min
BOD loading (lb/day/1,000 cu ft aer. tank vol.)	Conv. (Table I)	26.7	24.9	34.0	19.2	52.0	13.7
	Reaer. (Table II)	57.0	43.0	77.3	33.7	158	22.7
Mixed liq. aeration period (hr)	Conv. (Table I)	6.36	6.1	7.79	5.05	9.27	3.3
	Reaer. (Table II)	2.49	2.15	3.68	0.66	5.79	0.42
BOD red. by act. sl. process alone (%)	Conv. (Table I)	87.2	91.0	93.7	89.4	95.0	77.1
	Reaer. (Table II)	87.1	88.6	90.8	84.8	96.5	73.7
BOD loading (lb/day/100 lb sol. under aeration)	Conv. (Table I)	22.1	18.0	32.1	15.1	49.9	10.1
	Reaer. (Table II)	20.7	18.8	30.5	10.8	49.1	8.7
Air used (cu ft/lb BOD removed)	Conv. (Table I)	812	773	905	700	1,600	435
	Reaer. (Table II)	1,010	955	1,240	823	1,540	675

fore it is necessary to run more digester liquor.

The data on air consumption in Tables II and IV include not only the air actually used in aeration and reaeration tanks, but also any air used for return sludge airlifts, channel aeration, etc. Opinion differs as to whether air used for the latter purposes is as effective in oxidation as is that introduced directly into the aeration tanks. At Belleville (25) about 17 per cent of the air is utilized for channel aeration, 21 per cent for sludge reaeration, and 62 per cent for mixed liquor aeration. At Durham (26) there are no aerated channels or airlifts; 10 per cent of the air is used for sludge reaeration and 90 per cent for mixed liquor aeration. At Peoria (22) 28 per cent of the air is used for sludge reaeration and 72 per cent for mixed liquor aeration. Similar data are unavailable for the other plants.

At all of the reaeration plants except Peoria and Salem, the air is introduced near the bottom of the aeration tanks through one or another of the common types of diffusers. At Peoria only two-thirds of the air is so introduced, the remainder being fed through valved orifices located along the opposite side of the tank approximately 6 ft below the liquor surface. This practice makes possible a material reduction in power consumption, but requires a dual-pressure air supply and more complex piping. At Salem, the air is introduced through sparger rings located immediately below mixer aerators, which are motor-driven rotors of special design. Obviously, power is required for driving the motors as well as for compressing the air.

Comparison of Reaeration with Conventional Operation

In Table VI the long-period average results of the conventional plants in Table I are compared with similar results of the reaeration plants in Table II. However, the historical reaeration plants (Houston and Topeka) are omitted from the comparison. From Table VI it is clear that plants utilizing reaeration are operating successfully with BOD loadings per unit volume of aeration tank that are at least twice as great as those handled in plants that do not practice sludge reaeration. Mixed liquor aeration periods in the reaeration plants are little more than one-third of those employed in the conventional plants.

According to the recent manual "Sewage Treatment Plant Design" (27), ". . . the removal of BOD by the activated sludge process is related directly

to the weight of total or volatile activated sludge solids carried under aeration and inversely to the BOD input to the aeration tanks. As long as the average daily BOD load from municipal sewage does not exceed about 50 lb per 100 lb of suspended solids in the aeration system, a BOD reduction of about 90 per cent of the applied BOD can be expected." Table VI indicates that the BOD-to-solids loading in the reaeration plants was almost identical with that in the conventional plants. Therefore, if the previously quoted hypothesis is correct, the two types of plants should effect substantially equal BOD reductions. However, Table VI does not entirely confirm that hypothesis for, although the average BOD reduction was the same for both types, the median and quartile values for the reaeration plants were 2 to 4 per cent less than those for the conventional plants. Air consumption was approximately 25 per cent greater in the reaeration plants than in the conventional ones.

An analysis of data comparing BOD reduction and BOD loading apparently reveals that conventional operation is preferable to reaeration when operating at BOD loadings of less than 25 to 30 lb/day per 100 lb of solids under aeration. However, if the sludge inventory is reduced so that the BOD loadings range from 30 to 50 lb/day per 100 lb of solids under aeration, the two processes are substantially equal in performance.

As was to be expected from the earlier paper (5), the data further show that air consumption increases rapidly at reduced BOD-to-solids loadings. However, the data also show that for any given loading the reaeration plants generally required more air than did the conventional plants. This is so surprising that confirmation is needed before it can be accepted. Although Tables I and II contain extensive lists of conventional and reaeration plants, respectively, neither is complete. Chronologically their data are a decade apart; they apply to different communities, hence to different sewages. There are wide differences in the duration of the periods covered by the averages reported in the two tables. Possibly these differences are so great as to make comparison invalid.

Fortunately, Bender (20) has supplied sufficient data on the operation of the Indianapolis plant to permit an entirely separate comparison between the conventional and reaeration processes. That plant is so arranged that the activated sludge process can be conducted in four entirely separate batteries—A, B, C, and D. Furthermore, each battery is so arranged that it may be operated in the conventional manner without sludge reaeration, as a step aeration plant, or as an extended reaeration plant. During the period 1957–59 all three procedures were followed in the operation of the B, C, and D batteries. Frequently a different procedure was followed in each battery. Table IV indicates the time the two reaeration processes were used in each battery. During the same three years, conventional operation was followed in battery B for 16 months, in battery C for 12 months, and in battery D for 3 months. Thus, monthly averages for a total of 31 months of conventional operation are available. Table VII compares them with those for the 22 months of extended reaeration operation and the 47 months of step aeration. Again the BOD loadings per 100 lb of solids under aeration were substantially identical, but in this case air consumption for conventional operation was 25 per cent greater than for the sludge reaeration processes; that is, just the reverse of the comparison made in Table VI. Therefore, the original conclusion is maintained that for a given BOD-to-solids loading, the air consumption will be substantially the same regardless of whether or not sludge reaeration is practiced.

Like those in Table VI, the Indian-

apolis data show that conventional operation gave BOD reductions 2 to 4 per cent higher than were obtained with either extended reaeration or step aeration. The Indianapolis plants operated so seldom at loadings in excess of 30 lb BOD per day per 100 lb of sludge solids that it is difficult to draw any conclusions from its data. However, it does appear that again this difference is negligible at the higher BOD-to-solids loadings.

Table VII indicates that at Indianapolis there is no significant difference between conventional operation and sludge reaeration insofar as nitrification is concerned. Presumably this would be true for other plants and sewages; however, the data necessary for such comparisons are not available.

Hood (28) and Zablatzky *et al.* (18) state that by proper application of sludge reaeration procedures, the frothing of aeration tanks can be eliminated or at least minimized.

Perhaps the most striking comparison between conventional operation and sludge reaeration is based on the experience of the communities that have utilized both. Nelle (4) advises that Illinois has at least 15 operating plants that utilize sludge reaeration. In each instance the plants were originally constructed as conventional plants, without sludge reaeration, and were so operated until they became overloaded. Then piping and other minor changes were made to permit the use of sludge reaeration in one form or another. In each case the use of sludge reaeration materially increased the plant's capacity. In two instances (Peoria and Salem) the increase was so great that those plants now use only one-half of their total aeration tank volume.

During 1956, with sludge reaeration, the Peoria plant handled almost twice as great a BOD input in two aeration tanks as it could handle in four aeration tanks during 1936 without sludge reaeration.

At Belleville the Kraus process was placed in operation during 1956. Knoebel (25) states:

> As reported in the 1955 Summary, sewage received at this plant is high in dissolved wastes, particularly carbohydrates, and the

TABLE VII.—Comparison of Various Modes of Operation at Indianapolis During 1957–59

Item	Operation Process	Avg	Median	High Quartile	Low Quartile	Max	Min
BOD loading (lb/day/1,000 cu ft aer. tank vol.)	Conventional	29.8	26.2	36.3	21.5	52.6	14.4
	Extend. reaer.	41.2	37.4	46.0	33.9	68.2	29.6
	Step aer.	37.7	36.0	45.1	27.3	58.7	13.5
Mixed liq. aeration period (hr)	Conventional	3.15	3.1	3.7	2.5	4.4	2.0
	Extend. reaer.	2.02	2.04	2.23	1.83	3.12	1.31
BOD red. by act. sl. process alone (%)	Conventional	90.6	91.6	92.7	88.4	95.1	84.2
	Extend. reaer.	88.1	88.0	89.8	85.9	91.7	95.1
	Step aer.	87.7	87.8	89.9	85.3	93.2	80.7
BOD loading (lb/day/100 lb sol. under aeration)	Conventional	20.7	18.6	25.5	15.8	38.8	12.0
	Extend. reaer.	21.2	20.3	23.5	18.5	28.2	16.9
	Step aer.	19.9	19.1	24.0	14.5	42.3	9.1
Air used (cu ft/lb BOD removed)	Conventional	1,360	1,280	1,550	1,040	2,310	812
	Extend. reaer.	1,030	967	1,180	899	1,430	735
	Step aer.	1,160	1,050	1,400	914	2,430	621
NO_3-N in effl. (mg/l)	Conventional	2.35	2.16	3.57	1.31	4.65	0.40
	Extend. reaer.	2.06	1.87	2.63	1.12	5.06	0.58
	Step aer.	2.31	2.05	3.33	1.05	6.02	0.32
Sludge density index	Conventional	1.03	1.08	1.22	0.89	1.89	0.64
	Extend. reaer.	0.93	1.02	1.19	0.79	2.08	0.45
	Step aer.	1.01	1.05	1.33	0.93	1.82	0.68

TABLE VIII.—Annual or Period Average Values of Sludge Density Index

Plant Type	Sludge Density Index						
	No. Reported	Max	Min	Avg	Median	High Quartile	Low Quartile
Conventional	38	2.63	0.43	0.90	0.99	1.43	0.65
Reaeration	29	2.45	0.69	1.11	1.09	1.49	0.90

resulting activated sludge has poor settling properties. Such a sludge is difficult to retain in both final sedimentation and primary sedimentation, to which the excess is wasted. The sludge volume index is a measure of the settling properties of this sludge, the higher the number the poorer the settling. During the time in 1956 when this installation was in use the sludge volume index averaged 74 as against an average of 190 for 1955. At times in 1955 when this index rose to 300 and the daytime flows to final sedimentation approached 1,000 gpd per sq ft of tank area, retention of sludge in the system was impossible. This process has not only kept sludge in final sedimentation, it has improved suspended solids reduction in primary sedimentation, and contributed to a degree in reduction of basin capacity needed in aeration.

Concerning their experience at Austin, Tex., Ullrich and Smith (9) state:

> The treatment of Austin, Texas, sewage in the conventional activated sludge plant was difficult to control. Sludge bulking was the most serious problem. Bypassing of some primary effluent during peak flows and peak loads helped control bulking but even this failed to eliminate it at all times. . . .
>
> Treatment of the sewage in the enlarged and remodeled plant using the Biosorption process has been most satisfactory. The plant has given good BOD and suspended solids removals under widely varying conditions of loading and operation. No sludge bulking has been experienced and control has been easy and simple.

Sludge bulking as indicated by a low sludge density index * is not a problem at all conventional plants and at such plants sludge reaeration has little, if any, effect on the sludge density index. This is illustrated by the Indianapolis data given in Table VII. Unfortunately, Table I contains no data on sludge density indexes at conventional plants. However, an extensive tabulation of both annual and maximum monthly average indexes at conventional plants was published in 1942 (12). Table VIII compares those annual averages with the average indexes for the modern reaeration plants listed in Table II.

Although such a comparison indicates that sludge reaeration is effective in increasing the average sludge density index, it does not show its true value as an aid to the operation of the activated sludge process. In that process, it is the minimum index and not the average index that causes operational problems. Table IX compares monthly indexes at conventional and reaeration plants and, therefore, better illustrates the advantage of sludge reaeration as an operational procedure at plants where bulking may be a problem.

Final Clarifier Performance

Much data on the loading and performance of final clarifiers were accumulated (Table III) during the survey of reaeration plants. Generally speaking, final clarifiers give the most

TABLE IX.—Monthly Average Values of Sludge Density Index

Plant Type	Monthly Avg Sludge Density Index					
	Max	Min	Avg	Median	High Quartile	Low Quartile
Conventional	2.13	0.18	0.45	0.47	0.86	0.35
Reaeration	1.76	0.40	0.67	0.69	1.01	0.51

* "Units of Expression for Wastes and Wastes Treatment," Water Pollution Control Federation Manual of Practice No. 6, Washington, D. C. (1958) recommends the use of sludge density index, which is 100/SVI. Reported data have been changed to conform to this reference.

trouble when they are handling a mixed liquor having a low sludge density index. Inasmuch as sludge reaeration is effective in limiting and controlling that index, however, the clarifier data may not be as enlightening as would be similar data from conventional plants.

The three parameters commonly used in the design of sedimentation basins are (*a*) weir overflow rates, (*b*) surface settling rates, and (*c*) detention or theoretical displacement periods. With respect to the activated sludge process, opinion differs as to whether these parameters should be applied to the sewage flow alone, or to the mixed liquor (sewage plus return sludge) flow. According to the Ten States Standards (2) and the Pennsylvania Sewerage Manual (3), they should be applied to the sewage flow alone; therefore, that practice was followed in preparing Table III. However, the table also shows the average rate of sludge return as a percentage of the sewage flow. Turbulence at the inlet to any clarifier is greater at high rates of sludge return. Such turbulence may decrease the effectiveness of the unit.

As regards weir overflow rates, both of the standards (2) (3) limit them to 10,000 gpd/ft at small plants and preferably to not more than 15,000 gpd/ft at larger plants. With the exception of Decatur, Durham, and the two New York City plants, this latter limit was not exceeded at the plants reported in Table III. The extremely high rates (in excess of 140,000 gpd/ft) used at New York City are an exception to general practice. The New York tanks are of special design (29) and this fact, when coupled with the mode of operating the step aeration process at New York, probably explains why they are permissible in those plants. The Decatur clarifiers are more than 30 yr old and are not as well designed as most modern clarifiers. This is particularly true of their inlets. In 1956 the length of the effluent weirs was quintupled, thus reducing weir overflow rates from 33,000 to 8,000 gpd/ft. As indicated in Table I, this improved suspended solids removals was from about 44 per cent before the change, to about 70 per cent afterward. It also made a corresponding improvement in BOD reduction from about 82 to about 87 per cent. Durham is a new plant but employs a high weir rate, in the order of 30,000 gpd/ft. With the exception of Decatur, it is the only modern reaeration plant reporting a suspended solids reduction of less than 83 per cent through the activated sludge process alone.

The Ten States Standards (2) and the Pennsylvania Manual (3) both recommend that surface settling rates be limited to 800 gpd/sq ft. In general, this rate was not exceeded at the modern plants reported in Table III. There appears to be no correlation between the variations in tank performance, effluent quality, and settling rates of lesser magnitude.

Neither of the previously mentioned standards makes any mention of detention periods, but they do state that the depth of final tanks should be not less than 8 ft. At such a depth, and with a surface settling rate of 800 gpd/sq ft, the detention period would be only 1.8 hr. With the exception of Salem, none of the plants reported in Table III operated with detention periods of less than 2.4 hr. There appears to be no correlation between the detention periods shown and either the tank performance or the effluent quality.

Oxygen is essential to the maintenance of sludge activity. It cannot be supplied to sludge held in the bottom of a final settling tank. Undue retention of sludge in final tanks may be deleterious both to the aeration phase and the settling phase of the activated sludge process. However, some time must be allowed for the sludge to settle in the final clarifiers. If that time is equivalent in effectiveness to 30 min of quiescent settling in a 1-l graduate,

the solids content of the return sludge would be equal to the sludge density index of the mixed liquor entering the clarifier. Thus, the ratio of the actual solids content of the return sludge to the sludge density index of the mixed liquor is an indication of whether or not sludge is being retained unduly in the clarifiers. In 1940 Bloodgood (30) stated that this ratio should not exceed 1.0, but in 1944 he felt that a ratio of 1.1 was permissible (31). In 1949 Kraus (32) stated that for sludges having a sludge volume index of less than 100 (sludge density index of more than 1) it might be as high as 1.2. Nevertheless, Table III indicates that in most of the reaeration plants this ratio was generally held below 0.8. The table does not indicate any correlation between ratios of 1.0 or less and either the effluent quality or the tank performance.

Air Consumption

Both the Ten States Standards (2) and the Pennsylvania Sewerage Manual (3) state that the normal air requirements of the conventional activated sludge process should be assumed to be 1,000 cu ft/lb BOD applied to the aeration process.* If the removal is assumed to be 90 per cent, on the foregoing basis the normal air requirements for the conventional process would be 1,110 cu ft/lb BOD removed. The data herein presented show both higher and lower consumptions. As previously discussed, it is believed that there is no essential difference between conventional operation and sludge reaeration insofar as air requirements are concerned. In either case, the quantity of air required per pound of BOD removed will vary with the BOD loading per 100 lb of solids carried under aeration (5) (27).

Many other factors, including the type and condition of diffusers, rate of air application per diffuser, and dissolved oxygen level maintained in the aeration tanks, may affect the quantity of air used. It would seem that the freshness of the return sludge might also be a factor, but the data herein contained do not indicate this to be the case as long as the ratio of the actual solids content of the return to the sludge density index of the mixed liquor is 1.0 or less.

Comparison of Sludge Reaeration Methods

As previously discussed, present methods of accomplishing sludge reaeration include the extended reaeration procedures, step aeration, and the Hatfield and Kraus processes. It is natural to inquire as to which method is best, but the answer is difficult to find. Although it is hoped that the data in Table II may be extensive enough to truly represent sludge reaeration performance as a whole, it is hardly adequate to warrant valid comparison of the four different reaeration procedures. This is particularly true in the case of the Hatfield process, because all the data for that procedure were collected at only one plant. Nevertheless, Table X is presented to facilitate comparison of the available data. In its preparation the Durham data were omitted because of doubt concerning Durham's classification as a Kraus plant.

As regards BOD loading per 1,000 cu ft of aeration tank volume, Table X indicates that the extended reaeration plants are operating at much higher loadings than are those of the other three types. Almost one-half of the data on extended reaeration were obtained at San Antonio, where raw sewage rather than settled sewage is treated. In contrast, one-half of the data on the Kraus process were collected at plants treating effluent from biological roughing filters. There is no reason why a step aeration layout similar to that illustrated by Figure 3

* WPCF MOP 6 also recommends air measurement to be reported as cubic feet of air per pound of BOD removed.

TABLE X.—Comparison of Various Sludge Reaeration Procedures

Item	Operation Process	Avg	Median	High Quartile	Low Quartile	Max	Min
BOD loading (lb/day/1,000 cu ft aer. tank vol.)	Ext. reaer.	83.8	104	114	41.1	158	34.5
	Hatfield	45.7	46.3	46.4	44.2	49.9	42.5
	Kraus	59.5	57.1	86.2	35.2	90.4	32.2
	Step aer.	33.7	33.4	37.0	29.5	45.1	22.7
BOD red. by act. sl. process alone (%)	Ext. reaer.	89.4	88.7	92.6	86.0	96.5	84.6
	Hatfield	84.0	84.4	84.1	82.6	88.5	80.1
	Kraus	87.2	86.2	92.2	83.3	92.9	82.5
	Step aer.	88.8	88.8	89.6	87.2	94.2	83.8
BOD loading (lb/day/100 lb sol. under aeration)	Ext. reaer.	28.3	30.2	35.5	22.5	41.6	9.0
	Hatfield	11.3	11.0	12.4	10.7	13.2	8.7
	Kraus	16.6	15.0	23.2	11.7	26.5	10.3
	Step aer.	25.7	21.5	26.5	18.5	49.1	10.2
Air used (cu ft/lb BOD removed)	Ext. reaer.	989	955	1,010	823	1,430	675
	Hatfield	781	779	807	744	817	700
	Kraus	1,160	1,110	1,200	1,040	1,540	850
	Step aer.	1,010	933	1,080	911	1,240	910
Sludge density index	Ext. reaer.	0.97	1.01	1.21	0.87	1.45	0.69
	Hatfield	1.61	1.61	1.76	1.49	1.82	1.43
	Kraus	1.56	1.64	1.89	1.47	2.22	1.05
	Step aer.	0.95	0.93	1.02	0.89	1.10	0.88
Mixed liq. aeration period (hr)	Ext. reaer.	1.04	0.65	1.94	0.52	2.18	0.42
	Hatfield	3.21	3.26	3.30	3.11	3.49	2.93
	Kraus	2.94	3.88	3.98	2.57	4.33	1.20
Sludge reaeration period (hr)	Ext. reaer.	4.20	4.35	5.27	2.73	5.70	1.60
	Hatfield	12.0	11.2	13.2	11.0	14.4	9.76
	Kraus	18.0	17.5	21.9	16.3	24.0	9.35

could not be operated as an extended reaeration plant. Obviously, therefore, the one process can handle just as big a load as the other. It is believed that any of the four procedures could be relied on to handle a load of at least 90 to 100 lb of settled sewage BOD per day per 1,000 cu ft of aeration tank volume.

Regarding percentage reduction in BOD and air consumption per pound of BOD removed, the extended reaeration and step aeration procedures appear to be about equal. Both appear to be slightly superior to the Kraus process, but this may be due to the fact that the latter has not been credited with the BOD load imposed on it by the digester supernatant or digested sludge it receives. Furthermore, Table X indicates that the Kraus process was operating at an appreciably lower BOD-to-solids loading than was either the extended reaeration or step aeration procedure. As previously discussed, this may well explain its higher air requirement.

Although the Hatfield process appears inferior to the others insofar as BOD reduction is concerned, its air consumption per pound of BOD removed was materially less than that of any of the other three. This is particularly surprising because it was also operating at a lower BOD-to-solids loading. It seems quite possible that with increased use of air the Hatfield process would be just as effective and efficient as the Kraus process.

Concerning sludge density index, Table X indicates that the use of either the Hatfield or the Kraus process will make it possible to maintain a higher index than could be done with the other two procedures. However, as previously shown, any of the four procedures offers a much better control of index than does conventional operation and so the difference between them may be of little significance.

The higher sludge volume indexes obtained in the Kraus and Hatfield processes are, no doubt, due to the addition of digester sludge or supernatant to their reaeration tanks. Because digester solids are heavier than normal activated sludge solids, they improve the settleability of the latter and thus increase its sludge density index. This action is purely physical. Raw sewage solids, or even an inert silt or clay, would have the same effect. In fact, the latter was used occasionally for that purpose prior to 1936 (33). However, the digester material is also high in ammonia nitrogen. When it is seeded with return activated sludge and aerated for long periods of time, the ammonia is converted to nitrates and the color of the digester solids is completely altered from their original black to a dark brown color closely resembling that of ordinary activated sludge (23). Return of this highly nitrified material to the mixed liquor gives an added source of oxygen which can be utilized if dissolved oxygen disappears or becomes extremely low in the mixed liquor aeration tank or final clarifier.

Theoretically, it would appear that the most effective use of the nitrified sludge would result from returning it to the mixed liquor aeration tank only during the period of peak BOD load. Although this is possible with the batch aeration system used at the Long Road plant of Penn Hills Borough (23), it is impossible in the Hatfield process and would add greatly to the complexity of operating the Kraus process. At most Kraus plants the flow from the reaeration tank to the mixed liquor aeration tank is substantially uniform throughout the 24-hr period.

The time required to produce this highly nitrified sludge, from a mixture of return activated sludge and digested sludge, is at least 12 to 15 hr. It is generally recommended that 24 hr be allowed for this conversion regardless of whether it is accomplished in a continuous-flow reaeration tank as used in the Hatfield and Kraus processes, or in a batch aeration tank as used in the Long Road plant. At Decatur there are three aeration tanks. One is used for reaeration and two for mixed liquor aeration. Hatfield (21) believes that better results would be obtained if the plant was so arranged that one-half instead of one-third of its aeration tank volume could be used for reaeration.

In 1938–40 it was shown at Grove City (34) that the return of a poor quality digester supernatant to the mixed liquor aeration tank was less deleterious to the activated sludge process than was its return to the primary sedimentation basin. Grove City did not have any provision for sludge reaeration. At the old Austin plant (9) it was found still more advantageous to return the supernatant to its very small reaeration tank. However, since then all supernatant has been completely excluded from the activated sludge process. It is believed that, in any plant making provision for sludge reaeration, the digester supernatant can best be treated by returning it to that tank. However, there is no convincing evidence that such supernatant need contain any more than the minimum of digester solids. In the Hatfield process at least, any advantage to be gained from the resulting increase in sludge density index is offset by the need for a much longer sludge reaeration period.

Of all the sludge reaeration procedures herein discussed, step aeration offers the greatest flexibility. A step aeration plant arranged as shown in Figure 3 can be operated as either a conventional plant, an extended reaeration plant, or a step aeration plant. With the incorporation of very little additional piping, it could also utilize either the Kraus or the Hatfield process. Such an arrangement, with its four-pass aeration tank, is suitable only for relatively large plants. Smaller

plants might have only two- or three-pass aerators and therefore might be less flexible. Attempts to operate the step aeration process by providing multiple inlets along a single-pass aerator are likely to fail because of excessive longitudinal mixing (18) (27). The use of transverse instead of longitudinal baffles has not proved successful in controlling longitudinal mixing (27). This fact should be remembered in the design of any type of sludge reaeration plant.

Summary and Conclusions

1. Sludge reaeration has been in use since 1917. Many of the early plants allotted only 10 per cent or less, of their total aeration tank volume to sludge reaeration and in such cases sludge reaeration did not prove to be of much benefit. Most of the modern plants using sludge reaeration allot from 33 to 75 per cent of their aeration tank capacity to that purpose and have proved themselves capable of handling far greater BOD loadings per unit volume of total aeration tank capacity than can be handled in conventional plants without sludge reaeration. Whereas 35 lb of BOD per day per 1,000 cu ft of aeration tank volume is generally accepted as the maximum permissible average loading for conventional plants, reaeration plants have operated at average loadings in excess of three times that figure without sacrifice of effluent quality.

2. Use of the previously mentioned criteria of BOD loadings per unit volume of aeration tank should be discouraged. The efficiency of the activated sludge process, as measured by BOD removal, is related directly to the weight of total or volatile activated sludge solids carried under aeration and inversely to the BOD input to the aeration tanks. For maximum efficiency and the avoidance of low sludge density indexes, it is widely accepted that the average BOD input should not exceed 50 lb/day/100 lb of activated sludge solids under aeration. A comparison of operational results of conventional plants with those practicing sludge reaeration indicates that at BOD-to-solids loadings of 30 to 50 lb per day, the two give substantially the same BOD reduction (that is, about 90 per cent). For some inexplicable reason the reaeration plants apparently yield BOD reductions 2 to 4 per cent lower than those obtained in conventional plants when the two are operating at BOD loadings of less than 25 to 30 lb/day/100 lb of sludge solids. Had data been available on the volatile content of the various sludges, they might have explained this anomaly. At equal BOD-to-solids loadings the two modes of operation yielded approximately equal degrees of nitrification when treating similar sewages.

3. It appears that within certain wide limits neither the sludge reaeration period nor the mixed liquor aeration period is of any real significance as long as the proper ratio of BOD-to-sludge solids under aeration is maintained. In sludge reaeration plants mixed liquor aeration periods averaging as little as 25 to 30 min appear to be just as satisfactory as longer periods, but the advisability of predicating designs on mixed liquor aeration periods of less than 30 min at average conditions is questioned. Sludge reaeration periods generally ranged from about 2 to 5 hr except in those designs in which large quantities of anaerobic digester supernatant or sludge are added directly to the reaeration tank. In these latter cases, reaeration periods of at least 18 and preferably 24 hr may be desirable, although some plants have averaged as little as 10 hr.

4. Air consumption per pound of BOD removed by either the conventional or the sludge reaeration plants is primarily a function of the BOD-to-solids loadings. However, it is also affected by a host of other factors and so direct comparisons between the two modes of operation are difficult. De-

spite some conflicting and widely scattered data, it is concluded that there is no essential difference in the total air requirements of the two methods of operation.

5. By changing from conventional operation to one of the various sludge reaeration procedures, the capacity of several existing plants has been materially increased without loss of efficiency. In some instances, the increase has been as much as two- to four-fold. This indicates the possibility of effecting substantial savings in the cost of new plants by providing for sludge reaeration.

6. Sludge bulking (that is, occasional periods of low sludge density index) is not a problem at all conventional plants, but where it does cause operational difficulty adoption of any of the various sludge reaeration procedures results in easier operation, a higher average sludge density index, and less periodical fluctuation in its value. This is true for all modern sludge reaeration procedures. However, those that also provide for the addition of anaerobic digester supernatant (or sludge) to the reaeration tank, yield somewhat higher sludge density indexes than do the others. As previously noted, they also require longer sludge reaeration periods.

7. Some claims are made that sludge reaeration minimizes frothing in aeration tanks. However, no data on frothing are presented in this paper.

8. The modern sludge reaeration procedures are given various names. In this paper they are classified under four headings; namely, "extended reaeration," "Hatfield process," "Kraus Interchange Process," and "step aeration." The latter two are or were patented, but the patents on step aeration have expired. The extended reaeration classification includes such process descriptions as "Biosorption," "contact stabilization," and "Ridgewood biological coagulation." The Hatfield and Kraus processes depend on the addition of anaerobic digester supernatant or sludge to the reaeration tank. There appears to be little choice between extended reaeration, step aeration, and the Kraus process, insofar as either BOD removal or air consumption is concerned when the three are operated at approximately the same BOD-to-solids loadings and if the Kraus process is credited with the BOD load imposed on it by the anaerobic digester material. Data on the Hatfield process were available from only one plant, which admittedly was operating with a sludge reaeration period less than was deemed desirable. Although they indicated somewhat lower BOD removals than were obtained with other reaeration procedures, they also indicated lower air consumption per pound of BOD removed.

9. Step aeration is by far the most flexible of the reaeration procedures. However, its successful application requires special precautions against longitudinal mixing in the aeration tanks. Transverse baffles may not prove satisfactory for that purpose and therefore longitudinal or around-the-end baffles are recommended between the various steps.

10. Some data on the performance of final clarifiers are presented, but they are limited to plants practicing sludge reaeration. Inasmuch as reaeration yields a higher sludge density index than does conventional operation, the data may not be of much significance. However, they indicate that neither variations in surface settling rates of less than 800 gpd/sq ft nor variations in detention periods of less than 2.4 hr have any significant effect on either clarifier operation or effluent quality. Some of the data did indicate that weir overflow rates should be limited to about 15,000 gpd/ft. However, the New York City plants, which incorporate clarifiers of special design, give excellent results with overflow rates in excess of 140,000 gpd/ft.

11. Although it is generally conceded that undue retention of sludge in the final clarifiers may be deleterious to either or both the sedimentation and the aeration phases of the activated sludge process, the data herein presented do not indicate any harmful effect as long as the actual solids content of the return sludge does not exceed the sludge density index of the mixed liquor entering the final clarifiers. The practice of sludge reaeration generally permits use of a lower solids concentration in the mixed liquor than would be required in conventional plants operating without sludge reaeration. In such cases, it will also permit use of a lower rate of sludge return than would be required to avoid exceeding this limit in conventional plants. However, high percentage rates of return may still be desirable in reaeration plants that are not fully loaded in order to avoid carrying an excessive inventory of sludge solids under aeration. This is particularly true of extended reaeration plants.

12. Modern sludge reaeration should not be confused with modified aeration or high-rate activated sludge plants, although both types of plants require less total aeration tank volume than do the conventional activated sludge plants. In general, reaertion plants operate at the same BOD-to-solids loadings as do conventional plants, effect approximately the same degree of treatment, and require about the same amount of air. In contrast, modified aeration or high-rate activated sludge plants operate at much higher BOD-to-solids loadings and, therefore, effect a lower degree of treatment. They require less total air than do the conventional or reaeration plants and frequently even less air per pound of BOD removed.

Acknowledgments

Grateful acknowledgment is given to those who responded to questionnaires and provided valuable assistance in this study.

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EFFECTS OF KRAFT PULP MILL WASTES ON FISH

Masaru Fujiya

In recent years, the many pulp mills built in Japan have been the source of serious liquid waste problems. As a result, extensive and intensive studies have been carried out to determine the effects of these wastes on fish, shellfish, seaweed, and other aquatic organisms from various points of view.

Among the studies carried out have been ecological researches on the lethal dose, avoidance reaction, and others. Physiological studies by the paper electrophoretic method of serum separation had already been performed on fish (1) (2). On the other hand, the effects on the activity of seaweeds for phosphorus assimilation and the calcium absorption by shellfish had been studied, and discussed physiologically. Although satisfactory results were obtained from these, a histo-pathological approach also would be necessary for investigating the effects on fish. Therefore, a cyto-chemical experiment was inaugurated to study the histo-pathological effect on fish exposed in the water influenced by the waste. It was deemed important to determine the toxicity of the waste to fish.

Method

The effects of the waste on fish were studied *in vivo* twice during the summer and fall of 1958. Figures 1 and 2 show the location of the Kraft process pulp mill at the innermost part of the bay, the two wastewater outfalls (A and B), and the study stations occupied during each study period. The main outfall (A) discharges 46,000 tons per day of wastewater, distributed over an area of about 800 m in radius. Generally, the COD concentration of the wastewater was about 300 to 800 mg/l. The distribution of the waste in the bay during the first experiment is shown in Figure 3; in the second experiment the concentration was a little lower because the survey was made after a heavy rain.

The sample fish, *Sparus macrocephalus*, of about 25-cm body length, were exposed for 12 or 24 hr in crawls at the stations indicated. The waste condi-

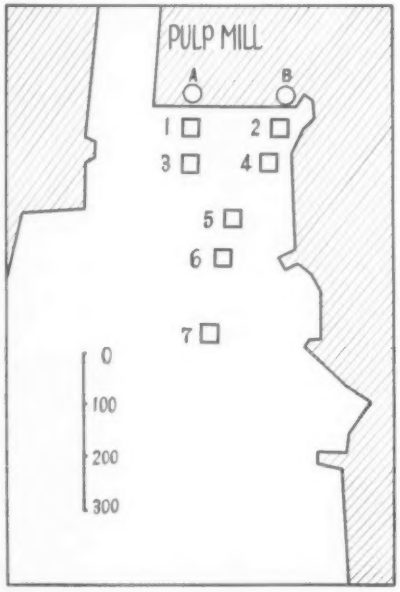

FIGURE 1.—Location of test stations for first experiment.

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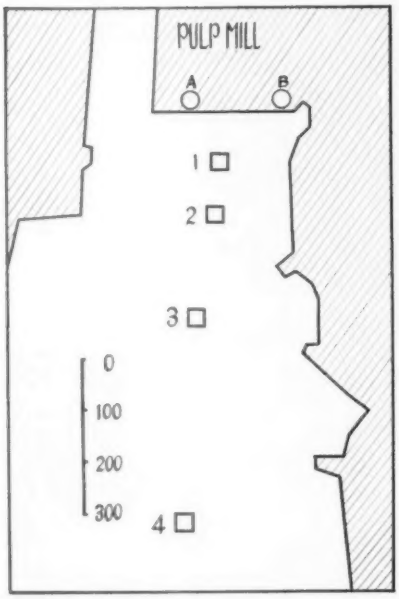

FIGURE 2.—Location of test stations for second experiment.

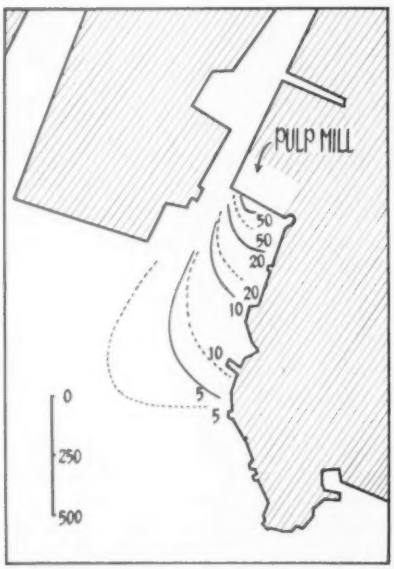

FIGURE 3.—Distribution of waste in the sea. Solid and dotted lines indicate COD concentration ranges of waste at mean and low tides, respectively.

TABLE I.—Conditions at Sampling Stations During First Experiment

Sta.	Dist. from Outfall (m)	Outfall	Contamination* Concentration	Duration of Influence	Ratio of Dead Fish†
1	100	A	Low	Always	1/4
2	100	B	Low	Always	2/3
3	300	A	Low	Sometimes	1/4
4	300	B	Low	Sometimes	0
5	500	A	Low	Seldom	1/4
6	500	B	Low	Seldom	0
7	800	A, B	None	—	0

* Measured in COD.
† Only surviving fish were studied.

tions at each station are given in Tables I and II.

The effects were studied by the following methods. The internal organs of the fish exposed in each station were removed and fixed in Carnoy's fluid.* Staining was done by the usual procedures, as follows:

1. Nitric acid and periodic acid (Schiff reaction of McManus-Lillie) for polysaccharide.
2. Pyronin-methyl green staining (of Kurnick) for RNA (ribose nucleic acids) and DNA (deoxyribose nucleic acids).
3. 5N-HCl Schiff reaction for DNA.
4. Turnbull-blue staining for iron.
5. Hematoxyline-eosin staining.

In the first experiment, the liver was the only material treated. In the second, however, the kidney, the spleen,

TABLE II.—Conditions at Sampling Stations During Second Experiment

Station	Distance from Outfall (m)	Contamination Concentration	Duration of Influence	Ratio of Dead Fish
1	100	Low	Always	0
2	200	Low	Sometimes	0
3	400	Low	Seldom	0
4	800	None	—	0

* Ethyl alcohol, 6 parts; chloroform, 3 parts; acetic acid, 1 part.

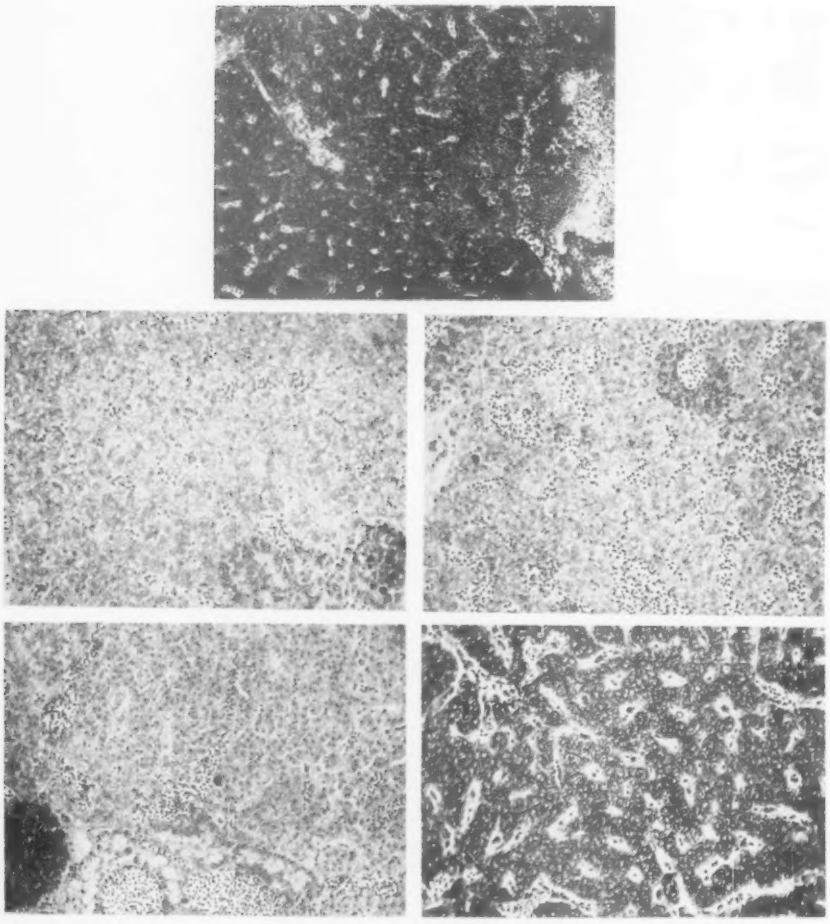

FIGURE 4.—Decrease of glycogen in liver of fish exposed at various distances from the outfalls: top, normal; left and right center, 100 m at 12 hr; bottom left, 300 m at 12 hr; bottom right, 500 m at 12 hr.

and the intestine were studied and compared histo-pathologically and cyto-chemically on the normal and the affected fish.

Results

Before the results obtained are discussed, the general structure of the organs studied should be explained.

Liver and Pancreas

Fish liver is situated in the front part of the body cavity, attached to the stomach, and usually is yellow, brown, or dark gray in color. In some species of fish the liver contains the pancreas, in which case it is called "hepatopancreas." *Sparus macrocephalus* is one of these fish; its liver is dotted with pancreas tissue. The pancreas, in the Glisson's sheath, surrounds the portal vein with appreciable RNA. The hepatic tissue of normal fish contains much polysaccharide and RNA. In particular, the nuclei and cytoplasmic vacuoles are surrounded

with much RNA, and it is considered that the polysaccharides in hepatic tissue are glycogens.

Intestine

In general, the histo-pathologic structure of fish intestine is the same as that of other animals classified as being of higher class than fish. It can be divided into four parts—mucosa, muscularis mucosa, muscularis, and serosa. There are many mucus-secreting glands (goblet cells) on the epithelia of the mucosa, as well as connective tissue in the muscularis mucosa. In general these structures have few differences from those of other higher-class animals.

Kidney

The kidney of the fish, situated in the back part of the cavity under the vertebral column, is a long and slender organ of red-violet color. Embriologically, its structure is mesonephros, and in comparison with other animals some differences are seen, especially in having many cell groups in the region of the urinary tubules.

Spleen

The spleen of most fish is situated beside the stomach, as in the case of other animals; but in some varieties it is at the intestine. Its function in fish is not known clearly, but it is generally believed that this organ shares with the lymph tissue in the formation of lymphocytes, and is also concerned in the destruction of waste erythrocytes.

Tissue Changes

It was expected that the fish affected by the waste would show recognizable changes in the liver, kidney, and intestine tissues, but that nothing notable would be found in the spleen.

The tissue changes are as follows:

1. Liver and Pancreas. Some notable changes are seen as the effects of the waste on liver, recognized histopathologically as follows (Table III):

(*a*) RNA in the liver. According to Szanto and Popper (3), normal human liver has appreciable RNA, surrounding the nuclei and vacuoles. Itikawa *et al.* (4) reported much more RNA can be found in horse liver. On the other hand, no RNA was observed in the case

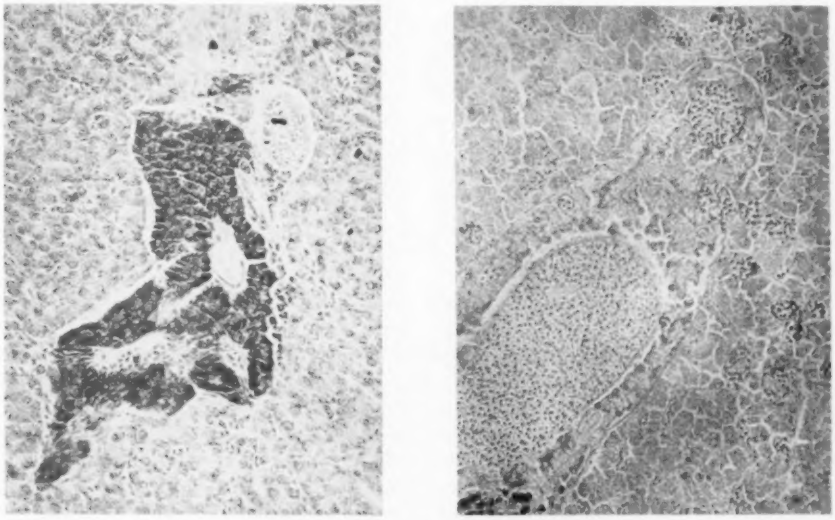

FIGURE 5.—Decrease in RNA in hepatic and pancreatic cells: left, normal; right, affected.

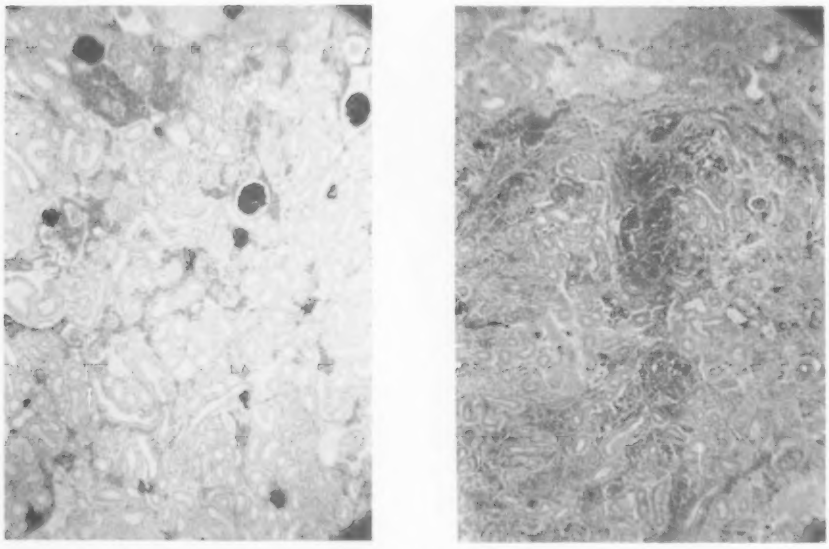

FIGURE 6.—Change in kidney tissue: left, normal; right, affected.

of poisoned liver by Stowell and Lee (5) and decrease was observed in various poisoned and diseased cases by Itikawa (4). Results show that the fish in contaminated sea water at a distance of 500 m from the outfall have scarcely any difference from normal fish, but that those inside the 500-m range have few or no RNA. Although Stations 3 and 4 were located the same distance from the outfalls, the fish at Station 3 show more RNA in the liver than those at Station 4. At the same time, there are also some differences between them in the average rate of dead fish, with 30 per cent for Station 3 and none for Station 4. Consequently, these results might be said to show the same tendencies as those obtained by the investigations previously cited.

(*b*) Polysaccharide in hepatic cells. The periodic acid Schiff reaction is a colorimetric method to discriminate between the polysaccharide and other saccharide groups. Namely, the highly polymerized carbohydrate, which includes the 1-2 glycol group, is oxidized to form the aldehyde group, which is colored by Schiff's solution. It may be considered that almost all polysaccharide compounds in the liver will be glycogen. A severe decrease of this material was observed in poisoning hepatitis by Stowell and Lee (5), and also in the liver poisoned by various toxic matter by Itikawa (6). Stowell and Lee (5) found that glycogen content in the liver under the effect of carbon tetrachloride increased during the first period of his experiment, and then decreased and disappeared.

Itikawa (6) noted that glycogen in the liver of mice given various dosages of each toxic material decreased, depending on the kinds and dosages of the materials. Therefore, there are different declines, in compliance with the characters of the toxic materials and their dosages.

Here, it could be observed that the normal fish have much glycogen in their livers; but it decreases when they are exposed in the water at 100 m and 300 m from the outfall, whereas the fish at Station 4 (300 m) have more glycogen than the fish at Station 3 (100 m), as is seen in the case of RNA.

TABLE III.—Effect of Kraft Pulp Mill Waste on the Liver of Fish *

					Hepatic Changes																							
					Hepatic Cells				Biliary Duct System					Arterial Vessel System					Portal Vein System							Pancreas	
Sta.	Dist. from Outfall (m)	Outfall	F. Pr. No.	Fish No.	RNA	Polysaccharides	Iron Deposition	Fatty Deposition	Enlargement	Degeneration of CT	Desquamation of Epithel	Atrophy	Cholangitis	Pycnosis of Endothol	Narrowness of Space	Desquamation of Endthel	Endarteritis	Degeneration and Edema of Media	Enlargement	Congestion	Leuconostasis	Lysis of CT	Hemorrhage Around Vene	Edema	Hemosiderin Thrombosis	RNA	Dissociation
Control	—	—	—	C-7-13	++++	+++	++	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	++++	−
				C-2	++	+++	++	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	++++	−
1	100	A	1	1-1	±	++	+	−	+	+	−	−	−	+	−	−	++	+	++	+	+	+	++	+	−	++	−
				1-2	+	±	±	−	+	+	−	−	−	−	+	−	−	−	+++	+	+	+	++	+	−	++	−
				1-3	±	±	±	−	−	−	+	+	−	−	−	+	++	+	+++	+	−	−	++	+	−	++	++
2	100	B	2	2-4	+	++	+	−	−	−	−	+	−	+	+	−	−	−	+++	+	+	+	+++	+	+++	+	++
				2-5	−	±	−	−	−	−	−	+	−	−	−	−	++	+	+++	+	+	+	+++	+	−	−	+++
				2-6	−	−	−	−	+	+	+	−	−	−	−	−	++	+	+++	+	+	+	+++	+	−	−	+++
3	300	A	3	3-7	++	++	−	−	−	−	−	−	+	−	+	−	−	−	+++	−	−	−	−	−	−	++	+
				3-8	−	+++	−	−	−	−	−	−	−	−	+	−	−	−	+++	−	−	−	−	−	+	++	+
				3-9	±	±	−	−	+	−	+	−	−	−	+	−	++	−	+++	+	−	+	−	−	−	++	+
4	300	B	4	4-10	++	+++	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	+	−	−	+++	−
				4-11	+++	+++	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	+	+++	−
5	500	A	5	5-13	+++	+++	−	+++	−	−	−	−	−	+	+	−	−	−	++	−	−	−	−	−	−	+++	−
				5-14	+++	+++	−	+++	−	−	−	−	−	+	+	−	−	−	−	−	−	−	−	−	−	+++	−
				5-15	++	++	−	+++	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	+	+	+++	−
6	500	B	6	6-16	++	++	−	+++	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+++	−
				6-17	++	++	±	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+++	+++
				6-18	+++	+++	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+++	+++
7	1,200	A, B	7	8-22	+++	++	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+++	−
				8-23	++	+++	−	+++	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+++	−
				8-24	++	+++	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+++	−

* Symbols in table are identified as follows: horizontal bar = negative; horizontal bar with half vertical bar = uncertain (negative or positive); horizontal bar with one vertical = lowest degree of positive; and horizontal bar with two, three, and four verticals = progressive degrees of positive.

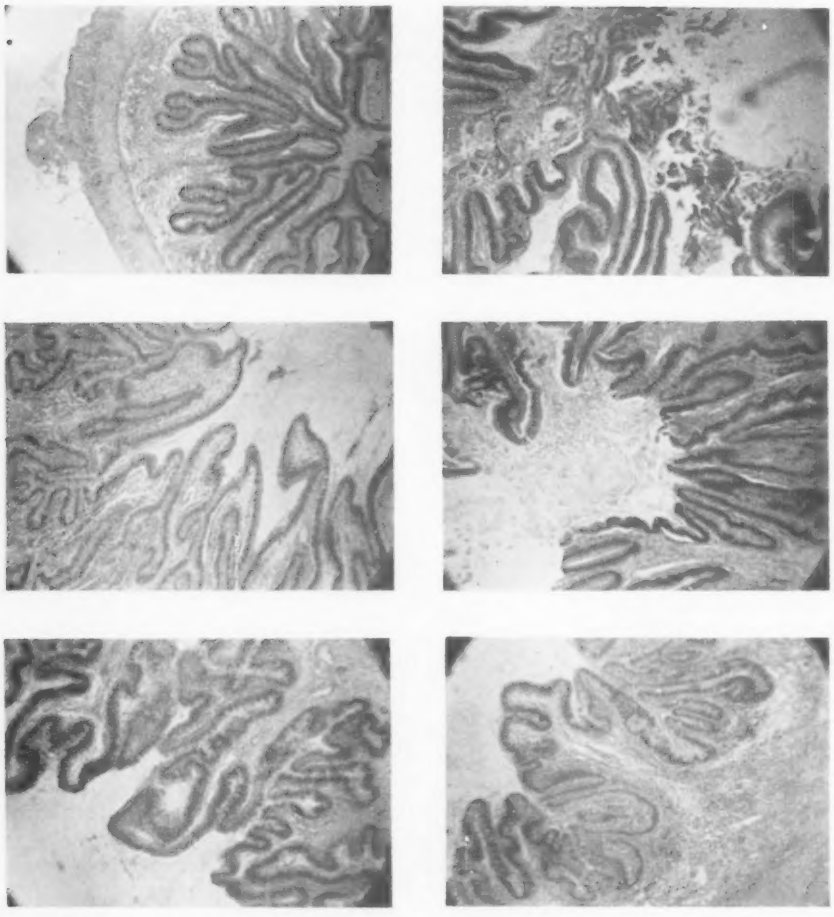

FIGURE 7.—Changes in intestine: top left and center left, normal; bottom left, accelerative secretion of goblet cells in affected fish; top right, desquamation of epithelia; center right, necrosis of epithelia; bottom right, degeneration of submucosa.

(*c*) Iron deposition in hepatic cells. An iron deposit was found in the hepatic cells of the normal fish, but never in affected fish.

(*d*) Change in biliary duct system. The epithelium of the biliary duct of normal fish has much polysaccharide in cells like the goblet cells, particularly on the edge of the epithelia, but in the fish exposed at Stations 3 and 4 there was a decrease in the quantity of polysaccharide. RNA was also held in the same part. In the fish at Stations 1, 2, 3, and 4 there was not only this decrease, but also enlargement, degeneration of connective tissue, and desquamation of epithelia. In addition, a few fish were taken with cholangitis, which was never seen on normal fish.

(*e*) Changes in arterial vessel system. The arterial vessel of Glisson's sheath was changed on the fish exposed at Stations 1, 2, 3, 4, and 5, showing pyenosis of epithelia, narrowness of space, atrophy, desquamation of epi-

thelium, and degeneration and edema of media, and in a few fish endoarteritis.

(*f*) Change in portal vein system. The undeniable symptoms of enlargement and congestion of the vein, edema, hemorrhage around the vein, and decomposition of connective tissue were observed in affected fish, especially at Stations 1, 2, and 3. It may be considered that the portal vein system is suffering harmful effects.

(*g*) Change in pancreas. The pancreas holds much RNA and no polysaccharide in normal fish. The fish at Stations 4, 5, and 7 have as much RNA as the normal fish in their pancreas.

Brachet (7) reported that RNA has high ability to synthesize some types of protein and reduction of RNA in the pancreas means a decline in the ability to synthesize protein. Further, the dissociation of pancreas structure found in the fish exposed at 100 m from the outfall may be considered to be a regressive change.

Among various ways to observe the symptom of any kind of change in the liver, it was considered that the observation of hypo- and a glyco-genesis was the most convenient way to determine the relation between the concentration of the waste and the degree of its effects on fish.

2. Intestine. In normal fish, the section of intestine usually appears as shown in two frames of Figure 7. In the affected ones, the accelerative secretion of goblet cells, desquamation of epithelia, necrosis of epithelia, and degeneration of submucosa (see Figure 7), were remarkable symptoms. In particular, necrosis and desquamation of epithelia and accelerative secretion of goblet cells were observed in most of the affected fish. Therefore, these symptoms were used as indicators to determine the effect of the waste.

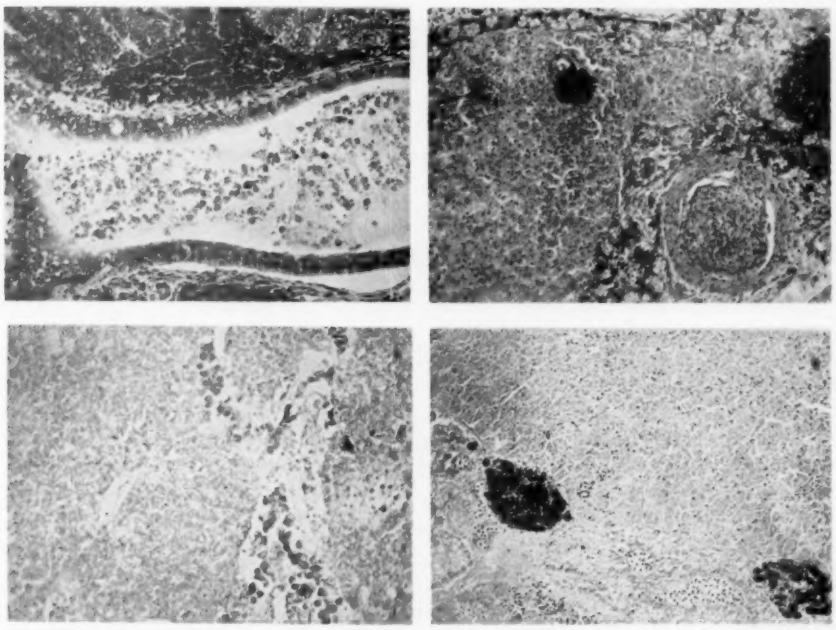

FIGURE 8.—Changes in other tissue observed: upper left, decidua cells in biliary duct; lower left, dissociation of pancreatic cells; upper right, endoarteritis, and thrombosis by organization, in liver; lower right, hemosiderin thrombosis in portal vein.

Necrosis and desquamation of epithelia were found in the fish exposed at Stations 1 and 2, whereas accelerative secretion of goblet cells was observed in all fish except the one exposed at Station 4. This method was considered a convenient one for estimating the effect on the intestine of fish, as well as a means of observing interesting and important symptoms in the fish.

3. Kidney. Among the varieties of change noted in the kidney tissue, the most remarkable was the degeneration to polysaccharide.

Discussion

It was possible to estimate that the RNA and glycogen in the hepatic tissue, and RNA in the pancreas, decreased gradually in inverse proportion to the distance from the outfall, and it is doubtless that the waste was toxic to the fish as is shown in the results reported by Stowell and Lee (5), Rosin and Daljanski (8), Szanto and Popper (3), and Itikawa *et al.* (4). In particular, the decrease of RNA may be estimated to give the harmful effect on protein synthesis as one of the most important symptoms of the effect of the waste on fish. On the other hand, the decrease in polysaccharides shows that the glycolysis in the body is expedited by something existing in the waste, influencing the metabolism of glycogen in the liver. Consequently, it may be considered also that the waste has a harmful effect on the development of the reproductive function as well as on growth. These problems are left for future studies. In addition, many kinds of effect observed in the circulatory system in the liver show that the effects of the waste on the fish are caused by the action of toxic substance in the waste.

Studies had been made on estimating the effects by the paper electrophoretic method of serum separation obtaining some results about the difference of the pattern between a normal fish and an affected one, as reported previously (1). It is certain from these results that some toxic substance in the waste produces deterioration in each organ through the circulatory system. Although the cause of the degeneration found in the affected kidney is not understood, it might be explained here as being effected through the circulatory system as previously mentioned.

Interesting and significant effects of the waste were found in the intestine, a part of the alimentary canal, because, according to some, marine fish take sea water into their bodies through the alimentary canal. Several types of effects observed around the intestine would give support to the theory, and moreover it would be one of the best ways to determine the degree of the effects of the waste.

In regard to the relation between the distribution of the waste in the sea and the effects on the fish, the effects of the waste in this field can be estimated from the consequences, as follows:

1. The fish exposed in the water-waste mixture of more than 10-mg/l COD show a harmful effect on the protein synthesis through a decrease of RNA in the pancreas.

2. The effect on the glycogen metabolism was recognized in the fish in water with COD of more than 50 mg/l.

3. Several effects on the circulatory system in the liver were found, suggesting that the waste contained something harmful to the system.

4. Necrosis and desquamation of epithelia were observed on the intestines of the fish at Stations 1 and 2, and accelerative secretion of goblet cells was found in those at Stations 1, 2, and 3. Therefore, the necrosis and desquamation are caused by the contaminated water of more than 50 mg/l COD and accelerative secretion of goblet cells by water with more than 10 mg/l COD.

5. The effluent from outfall A discharges stronger waste than outfall B, as the symptoms on the fish observed at

300 m from A and at 100 m from B were almost equal.

6. For the foregoing reasons, the histo-pathologically effective dose of Kraft process pulp mill waste to the fish is estimated to be the concentration of 10 to 50 mg/l in COD value.

Summary

1. The fish were exposed in crawls located in water contaminated by Kraft process pulp mill waste, and observed histo-pathologically.

2. The interior organs—liver, kidney, spleen, and intestine—were studied; each organ except the spleen was changed by the waste.

3. The principal changes were the decrease of glycogen in hepatic cells, the decrease of RNA in the pancreas, the degeneration to polysaccharide in the kidney, and the accelerative secretion and necrosis of epithelium in the intestine. These changes were used for the indicating symptoms to determine the effects of the waste on fish.

4. From the results, estimates were made not only of the effects of oxygen consumption by the waste, but also of its toxic function.

5. The histo-pathologically effective dose of the waste was estimated to be 10 to 50 mg/l COD, through the relation between the symptom of the fish exposed at each station occupied at various distances from the outfall of the mill and the distribution of the waste at the stations.

Acknowledgment

The author wishes to express his thanks to Dr. Osamu Itikawa, National Institute of Animal Health, for suggesting this research, especially the staining method and the methods of tissue observation.

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AMMONIA NITROGEN AND THE ANAEROBIC ENVIRONMENT

Orris E. Albertson

Much of the laboratory and field studies on anaerobic digestion has been concerned with describing the effect of environment on the rate of biological conversion of waste organic matter. Early recognition of the effect of temperature on the rate of biological assimilation led to the standard practice of providing heated digestion tanks. Mixing of the digester contents to promote a homogeneous mixture was also known to be a prime factor affecting the digestion, and in the past few years has been incorporated into all of the digestion processes operating in the "high-rate" zone. Torpey (1) first demonstrated a feasible method of concentrating raw sludges prior to digestion, a step which not only permits a large reduction in tank volume, but also promotes a stable, well-buffered digestion process.

Most of these experiments on the effects of temperature, mixing, detention *vs.* destruction, and thickened sludges were involved with the physical environmental factors and little or no concern was given to the chemical environment in the digester. It was only the last factor (thickened sludges) which had any noteworthy effect on chemical characteristics of the digesting sludges. These thickened sludges produced 3,000 to 6,000 mg/l alkalinity and the heavily buffered pH was normally 7.0 to 7.4. These characteristics differed greatly from conventional digestion, where a dilute sludge without thickening would produce 1,000 to 2,000 mg/l bicarbonate alkalinity and establish an equilibrium pH between 6.6 and 7.0.

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Review

Inasmuch as this represented an important change in the chemical environment, field testing at the recommended digester loadings for the various types of thickened domestic sewage sludges was considered necessary. Torpey (2) (3) digested combined primary with activated sludge and primary with modified aeration solids. The ability to thicken the modified aeration solids to concentrations greater than 10 per cent TS resulted in an alkalinity level above 7,000 mg/l with a pH of 7.6 at a loading of 0.12 to 0.15 lb VS/day/cu ft. Although no inhibitory effect of the high alkalinity concentration was definitely found, the possibility that it existed is shown in Table I.

Although the varying per cent volatile affected the per cent volatile solids destruction, there still appears to be some relationship between the lower reductions recorded at the higher pH and alkalinities. This increase in pH and alkalinity was also noted in the pilot-plant digestion of activated sludge just before a partial failure was recorded (3). The pH reached 7.2 and alkalinity was 5,000 mg/l, while the detention was lower than 3 days and the loading was above 1.0 lb VS/day/cu ft. However, the activated sludge feed averaged less than 5.5 per cent TS compared to the 10 per cent modified aera-

TABLE I.—High Alkalinity Digestion Data (Ref. 2)

Period	Loading (lb VS/day/cu ft)	Raw Sludge (% Vol.)	pH	Digester Alk. (mg/l)	Gas (cu ft/lb VS added)	VS Destroyed* (%)
June	0.157	70.4	7.6	6,900	9.3	53.3
July	0.154	67.1	7.5	6,700	10.3	59.0
Aug.	0.127	65.1	7.4	7,000	10.7	61.3
Sept.	0.150	74.2	7.3	6,100	11.2	64.0
Oct.	0.164	79.9	7.2	5,600	12.2	69.8

* Based on 17.5 cu ft gas/lb VS destroyed.

tion solids. The alkalinity concentration or production is a function of the per cent TS (actually per cent volatile solids) in the sludge and its nitrogen content.

Field pilot-plant studies were carried out at Middleboro, Mass. (4), where thickened primary plus biofilter sludge was fed to a high-rate digester during 1954–5. The experiment was inconclusive, although it did establish a hypothesis that high-rate digestion beyond the area now practiced may be inhibited by a by-product of digestion. It is possible that alkalinity, either as a direct poisoning agent or its presence (concentration), may be used as an indicator. This point was at loading level above 0.3 lb VS/day/cu ft. A particularly interesting observation was that volatile acids did not precede failure, but seemed to result after failure. The digester foamed violently at this point. The Jamaica sewage treatment plant (New York City), operating above the normal high-rate zone (0.10 to 0.30 lb VS/day/cu ft), encountered the same difficulty (5) (foaming and subsequent increased acids), but the digester recovered.

At the Grass Island treatment plant, Greenwich, Conn., the pilot-plant thickener and digester were set up to operate on primary sludge (6). This study did not reveal any inhibitory effects and digestion proceeded normally. The alkalinity concentration was less than 3,000 mg/l and the alkalinity production was quite low, even for primary sludge. The connected population at this plant was domestic, with no industrial waste present. Satisfactory operation was maintained at 1½ times the recommended loadings, or 0.3 lb VS/day/cu ft.

Table II gives alkalinity production for various types of sludges. These data show that detention has little effect on the destruction of protein matter, although it may affect the over-all reduction. This is also in agreement with Sawyer and Roy (7).

Schulze and Raju (8) carried on laboratory experiments attempting to establish the maximum rate of fermenting various low-molecular weight or-

TABLE II.—Alkalinity Production of Various Thickened Sludges

Location	Type of Sludge	Detention (days)	Loading (lb VS/day/cu ft)	Alk. Prod. (lb/lb VS)		Ref.
				Added	Destroyed	
Bowery Bay	Mod. aer.	31*	0.16	0.07	0.12	(1)
↓	Act. sl.	15*	0.18	0.11	0.20	(1)
	Act. sl.	14	0.20	0.10	0.18	(2)
↓	Act. sl.	2.6	1.18	0.10	0.42	(2)
Middleboro	Biofilter	16–30	0.22	0.066	0.15	(4)
Greenwich	Primary	11–20	0.32	0.033	0.05	(6)

* Average.

ganic acids. In a second series of experiments, to prevent pH suppression, they neutralized the volatile acids with ammonium and potassium hydroxide before adding them to the anaerobic digester. The organic substrate in the form of ammonium acetate, butyrate, etc., was added daily after the digester had reached equilibrium on the pure organic acid (that is, acetic acid, butyric acid). However, the volatile acids began to increase in the digester immediately following the addition of the ammonium or potassium salt of the organic acid. The gas production dropped off rapidly. The pH in this portion of the study was 7.4 to 7.8.

Mueller *et al.* (9), in an anaerobic digestion study, found that the gas production was seriously reduced as the alkalinity exceeded 4,200 mg/l ($CaCO_3$) and eventually reached about 6,700 mg/l. In this period the gas production fell off about 45 per cent and the volatile acids reached 3,700 mg/l as acetic acid. The pH was relatively stable at 7.4, although the volatile acids changed from 330 to 3,700 mg/l acetic acid. Although the significance is not known, it is interesting to note the change in components of the volatile acids occurring with the increased loading. As the loading was increased, the acetic acid decreased as a percentage of the total acid, whereas the propionic and butyric acid percentages increased. This led to the conclusion that the metabolism rate of propionic and butyric acids was less than the production, but acetic acid metabolism was greater than the production rate. Schulze and Raju (8) reported maximum metabolism ratios of propionic, acetic, and butyric acids to be 1 : 5 : 8 and quantitatively 0.2, 1.0, and 1.6 g/l/day, respectively. In these experiments the acids were added as pure organic acid solutions.

It has been long maintained that a pH of 6.8 to 7.2 is the optimum range for anaerobic digestion. This range was more or less arrived at by field observation of existing digestion facilities, although digesters have and do operate successfully outside this range. Within these limits of pH, no comprehensive studies have been published relating to the effect on the rate of digestion or biological metabolism. Heukelekian and Heinemann (10) studied methane-producing bacterial growth in terms of their maximum numbers, as related to the pH of the culture. Figure 1 shows a portion of these data. The pH had a tremendous effect on the number of bacteria, although this is not necessarily equivalent to the metabolism rate.

The pH of the digester has been shown to be directly proportional to the bicarbonate alkalinity and the percentage of CO_2 in the gas. The correlation as presented by Banta and Pom-

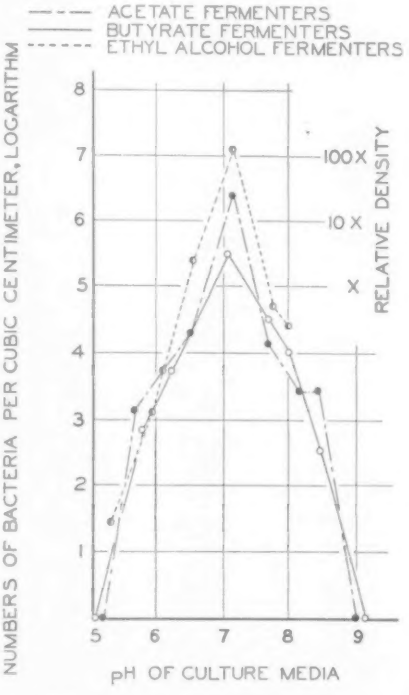

FIGURE 1.—Effect of pH on bacterial growth.

croy (11) may be rearranged as follows:

$$pH = 5.14 - \log (\text{per cent } CO_2) + \log HCO_3^- (\text{as mg/l } CaCO_3) \ldots (1)$$

Because the percentage of CO_2 in the digester gas is relatively constant over the different ranges of loading, the increase in alkalinity should increase the pH.

Thus, high-rate digestion of thickened organic sludges has brought on a new realm of biochemical environment within the digesters. Necessary control of external conditions has been recognized and successfully mastered, but the internal biological effect is still obscure.

There has been appreciable conjecture about the effects of thickening sludges and operating digesters beyond the high-rate loading range as it is now recognized. With the high activity present in these digesters and the highly buffered sludge, large changes in the volatile acids and bicarbonate alkalinity may occur before routine analysis detects them. The most popular theory is that the ammonia nitrogen present in digesting liquor becomes toxic to the methane organisms when the nitrogen concentration exceeds their tolerance level. Concentration of detergents by thickening has been considered a possible cause of failure, but no experimental proof is available. Torpey (3) was able to obtain 6.5 cu ft gas/day/cu ft of digester volume, which is equivalent to destroying 0.38 lb VS/day/cu ft. This is the highest rate of gas production reported, far surpassing the rates obtained where pure organic acids were fed to anaerobic cultures. This indicates that the maximum metabolism rates may be higher than yet attained.

Objective and Procedure—Series A

It is known that the advent of high-rate digestion has brought about some environmental conditions which evidently can affect the biochemical reduction of organic sludge solids. This so-called toxicity or poisoning occurs when the digester is loaded beyond the established high-rate zone. Thus, it is desirable to establish where this toxicity exists and what digester conditions are prevalent when this effect is noted. The purpose, then, was to maintain and operate laboratory-scale digestion units in a loading range above that now recommended, and to attempt to correlate those variables in the digesting sludge which will foretell a lowering of digestion efficiency.

Pilot Plant

Four laboratory-scale digestion units were operated in parallel. All were fed from the same supply of sludge, which was obtained from nearby primary sewage treatment plants. As shown in Figure 2, the four digestion units were enclosed in an incubator box made from insulation board. The box was provided with two glass windows to allow visual inspection and removable fronts for ease in removing the digestion units. The temperature was maintained relatively constant (±1°C) by a thermostatically controlled electric heating element. The heated air was circulated with a small fan.

Each digester was made from a 9-l Pyrex Woulff bottle, which has three openings at the top. These openings were used for the stirrer shaft, the gas vent, and the feed tube. Each bottle also had a ¾-in. tap at the bottom for sludge withdrawal. The feed line extended below the surface of the digesting sludge to prevent air from entering while feeding. Two flat blades, one at the surface to break up scum and the other at the bottom, were attached to the stirring shaft, which was driven off a shaft common to all four stations. A variac was used to control the speed of mixing. The gas produced was vented through a wet test gas flowmeter.

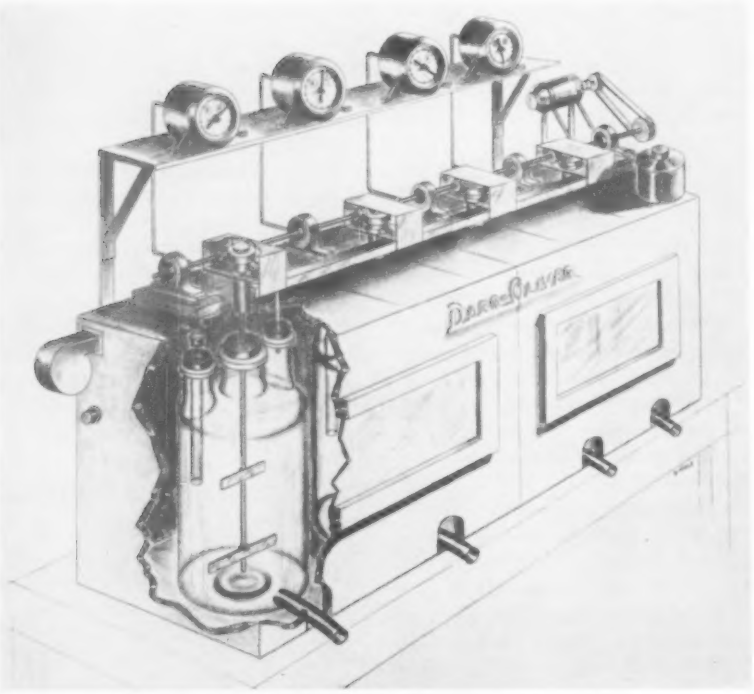

FIGURE 2.—Laboratory pilot-scale digestion unit.

Sludge Preparation

Thickening raw sludge was found to be difficult and impractical on the laboratory scale using gravity settling techniques. It was found, however, that the sludge would thicken rapidly to 8 to 10 per cent TS if placed on a 10-mesh screen. The solids in the drainage liquor can be recaptured by recycling it. Leaving the sludge on the screen overnight results in a solids concentration of 14 to 17 per cent. All of the sludge was thickened in this manner and then stored at 4°C.

Sludge used in these studies was obtained from the Darien and Grass Island (Greenwich, Conn.) sewage treatment plants. Both are primary plants with little other than domestic waste present. The raw sludge was warmed to 30°C and added to the digester after an equal volume of digested sludge was removed. The digesters were fed twice daily, 8 hr apart, when the loading ex-

TABLE III.—Raw Sludge Characteristics (per cent)

Source	Range of Tot. Sol.	Avg Vol.	Volatile Solids		
			Grease	Protein	Carbohydrates
Darien, Conn. (Series A)	5.7–14.9	77.0	23.1	19.6	57.3
Grass Is., Conn. (Series B)	8.2–10.3	82.0	18.2	17.5	64.3

ceeded 0.2 lb VS/day/cu ft. It was not practical to operate on a feeding schedule which would permit feeding more frequently than twice daily.

The average compositions of the raw sludges used in these experiments are given in Table III. The percentage of carbohydrates was obtained by difference. The pH of the sludge was quite low and the volatile acids high, but this has little effect on the digestion rate.

Digester Analyses and Calculations

The following daily analyses and records were kept on the operation of the laboratory-scale pilot-plant digesters: Raw and digested sludge; pH, alkalinity, volatile acids, ammonia nitrogen, organic nitrogen, grease, total solids, and volatile solids of both raw and digested sludges. Also measured were the amount of gas evolved and its CO_2 content. The analytical procedures used were those presented in "Standard Methods" (12). Due to the relatively high ammonia nitrogen concentrations present, it was found necessary to use more buffer solution than recommended. Otherwise, the values might be low.

Calculations for operating performance of the pilot digesters were largely dependent on the gas data. This was necessary because solids in the digester reflect, very slowly, any change in loading, particularly if this change is brought about by increased solids. It can be calculated theoretically that it requires 69 days for a mixed digester with 30-day detention to reach 90 per cent of solids stabilization following a load change. However, gas evolution may stabilize in 2 to 5 days. For this reason, the volatile destruction was calculated using the gas data and considering that 17.2 cu ft gas/lb VS destroyed was realized.

Experimental Results—Series A

The first part of this study was completed in the Westport laboratories. The objective at this point was to load the digesters with increasing concentrations of feed solids while maintaining 15 to 30 days detention until failure occurred. The loading was increased only after the gas production reached equilibrium, usually a period of 1 to 2 weeks. Table IV summarizes the data, according to loading periods where the loading exceeded 0.15 lb VS/day/cu ft. As shown, the four digesters were operated in pairs under different conditions of detention and loading. All of the digesters failed on or about April 14, but digesters 3 and 4 recovered after the loading was removed for five days. These probably would have failed also if the loading had not been removed. At this point all of the digesters were abandoned.

Hydrochloric acid was added to digesters 3 and 4 to determine if an inorganic acid would help speed recovery. The volatile acids in digester 4 did not exceed 3,000 mg/l following the addition of the HCl. Digester 3, the duplicate of 4, had acids exceeding 4,000 mg/l.

Weekly data may mask important changes in the digester, especially in a period where failure conditions predominate. Table V gives the maximum and minimum values of the data recorded during the week of April 7. These analyses were performed prior to the morning feeding schedule. During this week, the gas production fell off 20 per cent in digesters 1 and 2, but was stable in digesters 3 and 4. The acids were above 2,000 mg/l as acetic acid in digesters 1 and 2. Thereafter the increase in volatile acids above 3,000 mg/l inhibited the gas-producing organisms almost completely, except in digester 4.

At this time, foaming in the digesters became a problem. The principal characteristic of this foam or frothing was that it consisted of fine gas bubbles enclosing or attached to sludge particles. The gas bubbles did not coalesce and escape, which would then have allowed the sludge particles to resettle. The

TABLE IV.—High-Rate Digestion, Series A

Digester	Period* (1958)	Raw Sludge				Digester Biochemical Environment										
												Gas			Alk. Produced	
		VS Load (lb/day/cu ft)	TS (%)	VS (%)	pH	Det. (days)	Red. (%)	pH	Alk. (mg/l)	Vol. Acids (mg/l)	NH_3—N (mg/l)	(cu ft/lb VS added)	(cu ft/ cu ft cap)	CO_2 (%)	(lb/lb VS dest.)	(lb/lb VS added)
1	2/10–2/21	0.16	5.7	75.5	5.10	17.2	61.2	6.90	2,410	255	—	10.5	1.64	37	0.077	0.047†
	2/24–3/12	0.19	5.7	75.5	4.95	14.5	72.3	6.75	2,320	303	447	12.4	2.07	37	0.110	0.080†
	3/17–3/25	0.28	13.8	77.0	5.16	24.0	67.3	6.85	2,680	790	—	11.8	3.25	37	0.055	0.037
	3/26–4/6	0.35	14.4	78.9	5.00	20.0	64.0	7.00	3,820	697	927	11.0	3.85	34	0.069	0.044
	4/7 –4/13	0.44	14.9	71.4	4.95	15.0	49.9	7.10	4,980	2,495	1,231	8.6	3.75	33	0.102	0.050
↓	4/14–4/16	—	—	—	—	—	—	6.74	5,260	5,510	—	—	—	36	Failed	
2	2/10–2/21	0.15	9.4	75.5	5.15	30.0	68.8	6.95	2,470	193	—	11.8	1.73	36	0.068	0.046
	2/24–3/12	0.25	11.1	85.7	5.20	24.0	70.8	7.10	4,020	740	1,015	12.1	2.97	36	0.133	0.098
	3/13–3/25	0.28	13.8	77.0	5.16	24.0	69.4	7.10	4,470	648	1,176	11.9	3.27	38	0.074	0.051
	3/26–4/6	0.35	14.4	78.9	5.00	20.0	59.3	7.10	4,880	756	1,212	10.2	3.57	33	0.084	0.050
	4/7 –4/13	0.44	14.9	71.4	4.95	15.0	49.5	7.10	5,495	2,629	1,298	8.5	3.70	33	0.112	0.055
↓	4/14–4/16	—	—	—	—	—	—	6.60	4,880	6,750	—	—	—	39	Failed	
3	3/17–3/25	0.22	13.8	77.0	5.16	30.0	67.2	6.85	2,530	761	—	11.8	2.58	36	0.058	0.038
	3/26–4/6	0.29	14.4	78.9	5.00	24.0	69.8	6.90	3,560	762	982	11.8	3.43	34	0.051	0.035
	4/7 –4/13	0.27	14.9	71.4	4.95	24.0	75.1	7.15	4,965	1,988	1,300	12.7	3.19	33	0.112	0.084
↓	4/14–4/16	—	—	—	—	—	—	6.95	5,700	4,000	—	—	—	35	Failed‡	
4	2/10–2/21	0.15	9.4	75.5	5.15	30.0	67.2	7.00	2,730	200	—	11.6	1.70	36	0.083	0.056
	2/24–3/12	0.20	11.1	85.7	5.20	30.0	69.8	7.05	3,560	707	982	12.2	2.38	37	0.116	0.078
	3/13–3/25	0.22	13.8	77.0	5.16	24.0	75.1	7.10	4,130	752	1,029	13.2	2.88	36	0.072	0.054
	3/26–4/6	0.29	14.4	78.9	5.00	24.0	59.4	7.15	4,680	1,040	1,200	10.2	2.96	33	0.092	0.054
	4/7 –4/13§	0.27	14.9	71.4	4.95	24.0	63.1	7.20	5,710	1,941	1,398	11.4	3.10	33	0.128	0.082
↓	4/14–4/16	—	—	—	—	—	—	7.09	5,820	2,160	—	—	—	36	Partial Failure‡	

* Temperature failed on 2/20, 21°C.
† Septic sludge.
‡ Recovered after five days of no load.
§ On April 12 and 13 a total of 192 mg/l Cl^- (as HCl) was added to digester 4.

TABLE V. Digester Environment, Failure Conditions of April 7–13, 1958

Digester	VS Loading (lb/day/cu ft)	Det. (days)	pH	Alk. (mg/l)	Vol. Acids (mg/l)	NH_3—N (mg/l)	CO_2 (%)
1	0.44	15	7.01	4,820	1,788	1,230	30.9
↓	↓	↓	7.27	5,140	2,680	—	34.9
2	0.44	15	7.07	5,340	2,230	1,298	29.2
↓	↓	↓	7.18	5,580	3,020	—	36.3
3	0.27	24	7.08	4,580	1,680	1,300	24.9
↓	↓	↓	7.30	5,320	2,080	—	35.7
4	0.27	24	7.06	5,300	1,530	1,398	30.8
↓	↓	↓	7.24	6,040	2,540	—	35.3

froth never became hard, but was more or less fluid. Violent stirring dispersed the foam, but it returned with normal mixing. It was noted that mixing intermittently under high acid conditions with foaming tended to increase gas production.

Thus, many different conditions were prevalent during this impending failure; foaming started, pH and CO_2 fluctuated greatly, volatile acids were increasing, as was the alkalinity and ammonia nitrogen. An abnormally high rate of alkalinity production was also observed. The variation in percentage of CO_2—and probably in some of the other variables—was much greater over a day than shown in Table V. The CO_2 content of the gas increased to 45 to 50 per cent after the digester was charged. Although daily gas production figures were satisfactory, lack of surge in gas production following feeding indicated trouble ahead. This surge should take place even when 2,000 mg/l volatile acids are present, if digestion is going to proceed satisfactorily.

The digesters went through one or two increases in volatile acids accompanied by a drop in pH from about 7.4 to about 7.1 prior to failure. Although a small drop in gas production occurred, both immediately returned to normal. As the ammonia nitrogen increased, the pH climbed slowly to between 7.3 and 7.4 before it broke. This shift in equilibrium occurred in less than a day.

Objective and Procedure—Series B

Thus, the digesters in Series A failed at the high and low loading, but all were in the range of alkalinity where other researchers have claimed ammonia nitrogen to be toxic to digestion. This led to the second phase of the digestion study. Now it was desirable to remove or reduce the effect of a variable which might mask the environmental changes brought about by increasing concentrations of ammonia nitrogen. Therefore, a loading of about 0.2 lb VS/day/cu ft and a detention of 22 days were chosen. Since the sludge solids fed to the digesters proportional to this loading were about 8 per cent, the equilibrium ammonia nitrogen concentration was about 900 mg/l as nitrogen.

To establish whether or not the ammonia nitrogen per se was toxic, two different ammonia salts (NH_4HCO_3 and NH_4Cl) were used. These salts were added in various increments to the digesters until failure was recorded. In the pH range found in the digesters NH_4Cl would not enter into any chemical reaction. However, the NH_4HCO_3 concentration is controlled by the pH and the percentage of CO_2 (Equation 1) present, and under certain conditions of these variables the HCO_3 will be reduced as follows:

$$NH_4HCO_3 + CH_3COOH \rightarrow CH_3COO \cdot NH_4 + H_2CO_3$$

$$H_2CO_3 \rightleftarrows H_2O + CO_2\uparrow \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

TABLE VI.—Digester Environment at Failure, Sept. 1–7, 1958

Digester	Salt	pH	Total Alk. (mg/l)	Vol. Acids (mg/l)	NH_3—N (mg/l)	VS Des.* (%)
1	NH_4Cl	7.02	3,840	110	1,605	76.5
↓	↓	7.23	4,380	1,680†	1,980	↓
2	NH_4Cl	6.99	3,860	342	1,500	74.7
↓	↓	7.20	4,160	1,950†	1,870	↓
3	NH_4HCO_3	7.17	4,680	137	1,040	72.1
↓	↓	7.36	5,740	1,480†	1,310	↓
4	NH_4HCO_3	6.92	4,640	154	1,025	73.6
↓	↓	7.36	5,780	3,900	1,377	↓

* Over entire run.

† Acids increased to 3,000 mg/l or more by 9/12.

Thus, if the NH_4 ion is toxic, the four digesters should fail at the same point. As established in the first portion of this study, the critical ammonium nitrogen level should be 1,200 to 1,400 mg/l. The digesters were operated in duplicate with regard to the two ammonium salts; that is, two on NH_4Cl and two on NH_4HCO_3 supplement.

Experimental Results—Series B

The two digesters to which NH_4Cl was added eventually failed at 1,800 to 2,000 mg/l of ammonia nitrogen. However, no effect on gas production was noted when the addition rate was 100 mg/l or less per day. When this amount was increased to 250 mg/l for two days in succession, the acids increased and the digester failed.

The digesters receiving NH_4HCO_3 did not reveal any reaction at 1,250 mg/l as N. As the ammonia concentration exceeded this point, the acids increased rapidly until 2,900 and 4,100 mg/l were present. The loading was removed when the acids exceeded 2,000 mg/l, and 150 and 75 mg/l HCl was added to digesters 3 and 4. Digester 3 was then able to be returned to full load and digester 4 to half load after five days. Since the ammonium additions were stopped as the acids increased rapidly, the ammonia nitrogen concentration was about 1,350 mg/l. Table VI gives some of the significant data recorded when the digesters failed. Where two values are given, these represent the maximum and minimum values recorded.

The destruction rate was very high

TABLE VII.—Digestion Data, Series A

NH_3—N (mg/l)	VA (mg/l)	CO_2 (%)	pH		
			Actual	Predicted	Diff.
1,305	5,000	39.3	6.86	6.97	−0.11
1,270	3,810	35.8	7.03	7.06	−0.03
1,410	2,950	34.4	7.12	7.15	−0.03
1,465	2,730	36.0	7.20	7.13	0.07
1,288	2,630	30.9	7.18	7.20	−0.02
1,175	2,350	30.9	7.27	7.16	0.11
1,285	2,235	35.0	7.12	7.11	0.01
1,166	2,030	24.9	7.30	7.30	0.00
1,118	2,010	33.2	7.12	7.09	0.03
1,200	1,940	35.7	7.12	7.07	0.04
1,175	1,788	34.9	7.07	7.09	−0.02
1,340	1,718	34.2	7.24	7.17	0.07
1,320	1,718	30.8	7.22	7.23	−0.01
1,304	1,528	30.9	7.24	7.24	0.00
1,105	1,064	34.5	7.10	7.10	0.00
1,116	1,012	36.5	7.12	7.07	0.05
1,140	980	28.3	7.17	7.26	−0.09
990	928	33.3	7.03	7.08	−0.05
933	670	33.3	7.06	7.08	−0.02
1,122	635	34.9	7.14	7.13	0.01
1,002	575	34.9	7.12	7.09	0.03
1,143	438	38.9	7.12	7.10	0.02
997	361	38.3	7.05	7.06	−0.01
773	345	35.0	6.93	7.00	−0.07
1,062	259	36.9	7.10	7.14	−0.04
1,110	241	38.8	7.15	7.13	0.02
447	232	37.5	6.77	6.73	0.04
					$\Sigma = 1.10$
					$\bar{X} = 0.04$
					$S = 0.05$

and averaged 74.2 per cent for the digesters. These digesters were fed the Grass Island sludge, which is quite high in volatile matter (see Table III).

Correlation of the Data

Much of the preliminary correlation of the data was done by hand and the basic form of the equation describing the biochemical equilibrium was recognized. However, to determine whether or not the best fit was being obtained, the data were subjected to a regression analysis by an electronic computer. The four variables included in the equation were pH, volatile acids, ammonia nitrogen, and CO_2 content of the gas. Because the biochemical balance can shift, each set of data represents values determined at the same time (that is, CO_2 content was measured just prior to removing the sample for the other analyses).

The pH was made the dependent variable and the computer established the following regressions for the data using this model:

$$\text{pH} = b_0 + b_1 \log \text{VA} + b_2 \log \text{NH}_3\text{–N} + b_3 \log \text{VA} (\log \% \text{CO}_2)$$

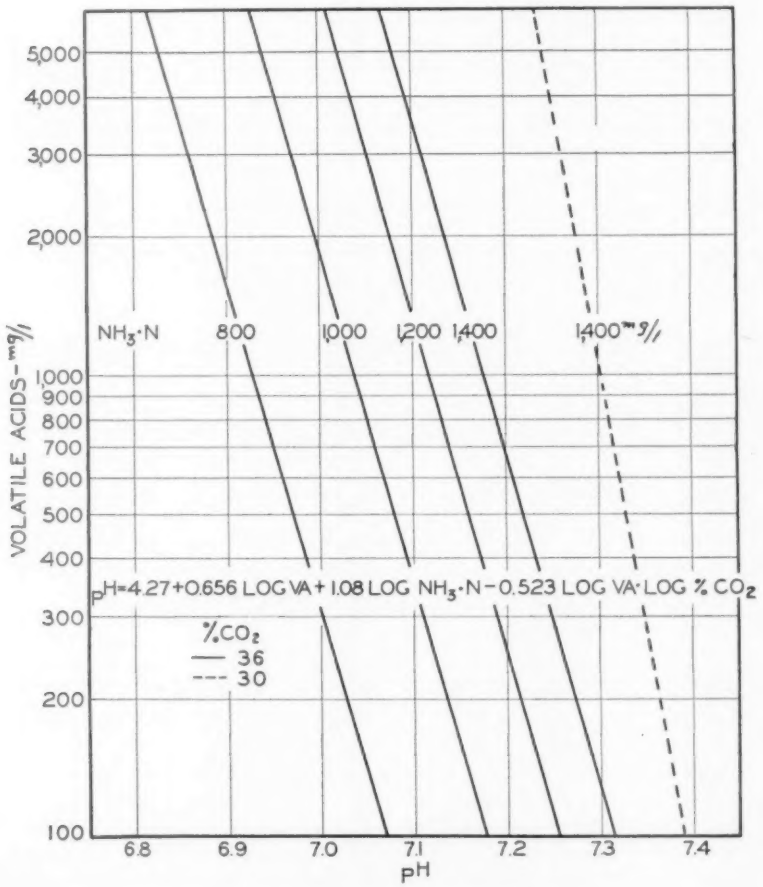

FIGURE 3.—Series A; high NH_3-N levels.

Series A

$$pH = 4.27 + 0.656 \log VA + 1.08 \log NH_3\text{-}N - 0.523 \log VA \log \%\ CO_2 \quad (3)$$

Series B

$$pH = 2.49 - 0.797 \log VA + 2.61 \log NH_3\text{-}N - 0.101 \log VA \log \%\ CO_2 \quad (4)$$

Tables VII and VIII give the pH values predicted from Equations 3 and 4, respectively, using the other three measured values. For Series A, the average deviation was 0.04 pH unit, with a standard deviation of 0.052 pH unit. Equation 3 accounts for 82.4 per cent of the variability in the data. The average deviation in Series B was 0.06 pH unit, with a standard deviation of 0.08 pH unit. Equation 4 accounted for 87.2 per cent of the variability. It is not possible to obtain a good correlation of the data by combining Series A and Series B. The coefficient before log NH_3-N changes greatly from Equation 3 to Equation 4, and is probably

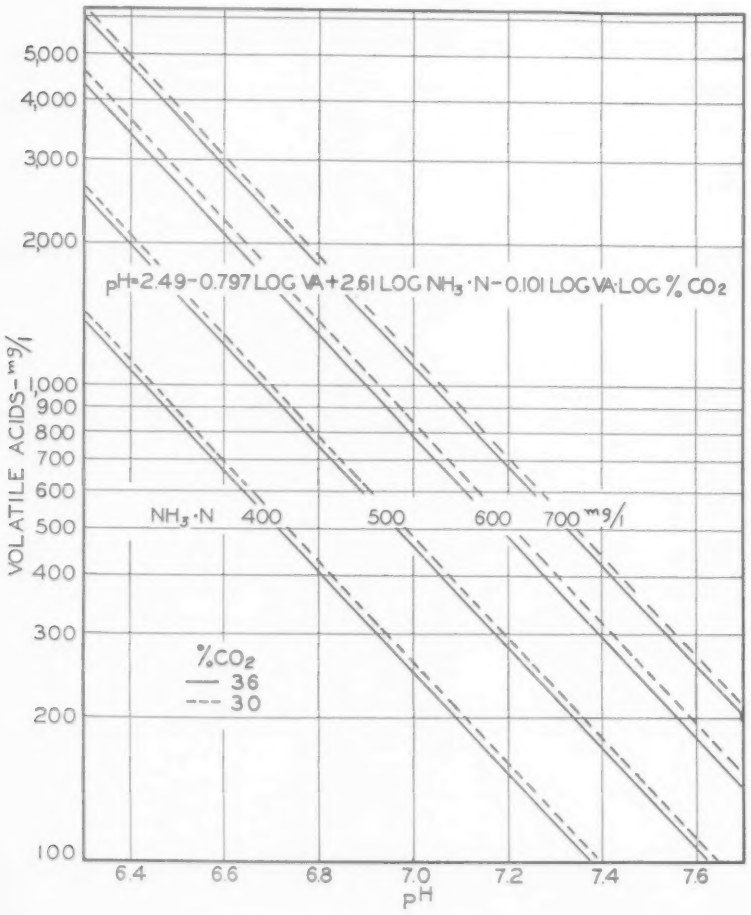

FIGURE 4.—Series B; low NH_3-N levels.

TABLE VIII.—Digestion Data, Series B

NH_3–N (mg/l)	VA (mg/l)	CO_2 (%)	pH		
			Actual	Predicted	Diff.
480	333	37.2	7.00	7.06	−0.06
558	462	36.2	6.97	7.10	−0.13
505	530	35.0	6.98	6.93	0.05
561	545	35.0	6.99	7.04	−0.05
488	642	40.9	6.95	6.80	0.15
545	497	39.7	6.96	7.04	−0.08
500	448	36.2	7.00	6.99	0.01
520	785	40.4	6.85	6.79	0.06
505	617	38.5	6.82	6.86	−0.04
510	858	40.2	6.72	6.73	−0.01
490	616	38.8	6.81	6.82	−0.01
512	805	36.4	6.82	6.77	0.05
483	932	46.0	6.70	6.63	0.07
513	1,105	41.2	6.74	6.63	0.11
500	1,470	36.2	6.64	6.63	0.01
530	1,660	31.5	6.44	6.53	−0.09
520	1,560	40.2	6.48	6.50	−0.02
560	1,980	38.1	6.38	6.49	−0.11
599	660	34.7	7.04	7.04	0.00
656	1,180	33.2	6.90	6.91	−0.01
583	792	33.5	6.96	6.94	0.02
650	920	31.8	6.94	7.00	−0.06
611	850	39.8	6.92	6.94	−0.02
632	1,310	37.6	6.88	6.81	0.07
615	1,185	43.9	6.66	6.80	−0.14
640	808	38.7	6.91	7.02	−0.11
625	814	40.8	7.06	6.98	0.08
660	643	37.1	7.15	7.16	−0.01
640	1,045	37.2	7.04	6.92	0.12
680	702	32.6	7.16	7.17	−0.01
675	751	34.6	7.21	7.12	0.09
720	728	31.6	7.30	7.22	0.08
					$\Sigma = 1.93$
					$\bar{X} = 0.06$
					$S = 0.08$

affected by the ammonia nitrogen concentration. Series A includes ammonia nitrogen data in the range of 900 to 1,400 mg/l, whereas Series B is 500 to 700 mg/l N. Combining the data of Series A and B produced an equation which accounted for only 59 per cent of the data variation. Change in the constant before the NH_3–N is the cause, as it is not a linear log function.

The Series A experiment (Equation 3) covered the range of nitrogen concentrations which resulted in failure of the digesters. If the CO_2 content is uniform, Equation 3 can be reduced to

$$pH = 4.27 - 0.158 \log VA + 1.08 \log NH_3\text{–}N \quad (5)$$

in which CO_2 content was 36 per cent. This manipulation reduces the variables to three and the equation may be graphed as shown in Figure 3. The effect of higher or lower CO_2 content is indicated. This is a function of the volatile acid concentration and increases as the log of volatile acids.

The percentage of CO_2 controlled the pH to a large extent in Series A, whereas in the second study the CO_2 had little effect on pH. This portion of the data (Figure 4) is greatly affected by the level of NH_3–N and the concentration of volatile acids. The effect of NH_3–N on the pH decreases as the concentration increases, as shown by the constant before the nitrogen term reducing from 2.61 to 1.08. Thus, the lines depicting constant NH_3–N would not be parallel, but rather more and more oriented to the vertical as the NH_3–N concentration increases. The steepest changes in slope would be at the lower NH_3–N levels.

To the original model, the term $b_4 \log \%\ CO_2$ was added. This did not increase the prediction accuracy, and gave the same average and standard deviations as the original regression.

Discussion

The main concern in this study was to determine the cause of digester failures when increasing concentrations of solids were added. The results of these experiments answered the following considerations:

1. The digester loading itself was not directly associated with the cause of failure. Failures were recorded at loadings of 0.20, 0.27, and 0.44 lb VS/day/cu ft. However, all of these failures had one condition in common, an NH_3–N concentration of 1,200 to 1,400 mg/l. This indicated that the NH_3 ion was at least an indicator of a difficult

TABLE IX. Comparison of High Solids Digestion Studies

VS Loading (lb/day/cu ft)	pH	Alk. (mg/l)	Vol. Acids (mg/l)	NH_3—N (mg/l)	Reference
0.04	7.9–8.1	25,000	800	5,000	(13)
0.11	7.4	6,400	2,000	—	(9)
0.15	7.4–7.6	6,900	500	1,700*	(2)
0.20	7.2–7.4	5,800	1,000	1,300	This paper
0.21	7.2–7.35	5,700	800	—	(4)
0.27	7.1–7.3	5,700	1,000	1,350	This paper
0.32	7.2–7.3	5,800	400	—	(5)
0.44	7.1–7.3	5,300	2,000	1,200	This paper
1.15	7.0–7.2	5,000	2,000	1,100*	(3)

* Estimated.

operating area, and possibly the cause. However, in the second series of tests the NH_3 ion was present as NH_4Cl, a stable salt, in concentrations exceeding the foregoing tolerance level without causing the digester to fail. This fact contradicts the toxicity theory, but does not preclude the possibility of the NH_3 ion, present as bicarbonate or acetate, from adversely affecting the digester environment by changes in the biochemical equilibrium.

2. The pH, NH_3–N, volatile acids, and percentage of CO_2 in the gas control the digester chemical balance. Unfortunately, it is difficult to visualize an equation where four variables and one interaction term are included. Unless one of the variables is relatively constant, it is impossible to graph the equation. However, in actual operation the digester produces gas of fairly uniform quality, unlike the pilot plant where the once or twice daily feedings caused large fluctuations in the CO_2 content. This was probably a factor which hastened failures.

Considering Equation 5, where the CO_2 content is a constant, it is obvious that an increase in the NH_3–N concentration should result in:

a. Increase in pH, volatile acids constant.
b. Increase in volatile acids, pH constant.
c. Increase in both pH and volatile acids.
d. Decrease in pH, volatile acid increase.

However, test observations indicate that only two different conditions exist, as follows:

a. The pH increases with the ammonia increase.
b. When the volatile acids do increase, they drive the pH down with a very rapid shift in equilibrium. The result is a new higher stable level of volatile acids and lower pH.

It is known that the volatile acids cannot exceed 2,500 to 3,000 mg/l without seriously affecting gas production. But why should the volatile acids increase when, potentially, sufficient biological activity is present to utilize these acids?

The increase in alkalinity level within the digester tends to increase the operating level of the volatile acids. That is, although 100 to 150 mg/l acids would be present at 1,000 mg/l alkalinity, about 300 to 600 mg/l volatile acids may be in equilibrium at 5,000 mg/l alkalinity. Although the methane bacteria are attempting to utilize the volatile acids, the acids also tend to combine with ammonia and form ammonium-acid salt which appears relatively stable. To account for the large shift in pH-volatile acid equilibrium, the methane producers must have been momentarily inhibited.

The only plausible solution is that some effect present during the equilibrium shift was inhibiting gas production. Yet, ammonia itself was shown to be only an indicator. The pH, prior to the times when the volatile acids increased rapidly, was 7.3 to 7.4 and excess acids reduced this to 7.1, where digestion was stable until the organic acids exceeded 2,500 mg/l. Thus, it appears possible that the optimum pH may be very close to 7.0. Then the pH would also be more critical as the loading (bacterial activity) increased. Few results on the digestion of high solids sludge are available for study. Some of these are given in Table IX. Data from Snell (13) represent a semi-batch experiment; the rest are for continuous pilot-plant or full-scale operation.

These same data (Figure 5) indicate that pH very likely becomes critical as the loading increases. The optimum pH approaches 7.1, or about the same value at which Heukelekian and Heinemann (10) were able to obtain the maximum number of methane-producing bacteria. A digester can operate at a low loading at pH 6.6, but it is doubtful whether digester control would be possible under this condition at a high loading.

This self-neutralization could account for the increase in volatile acids

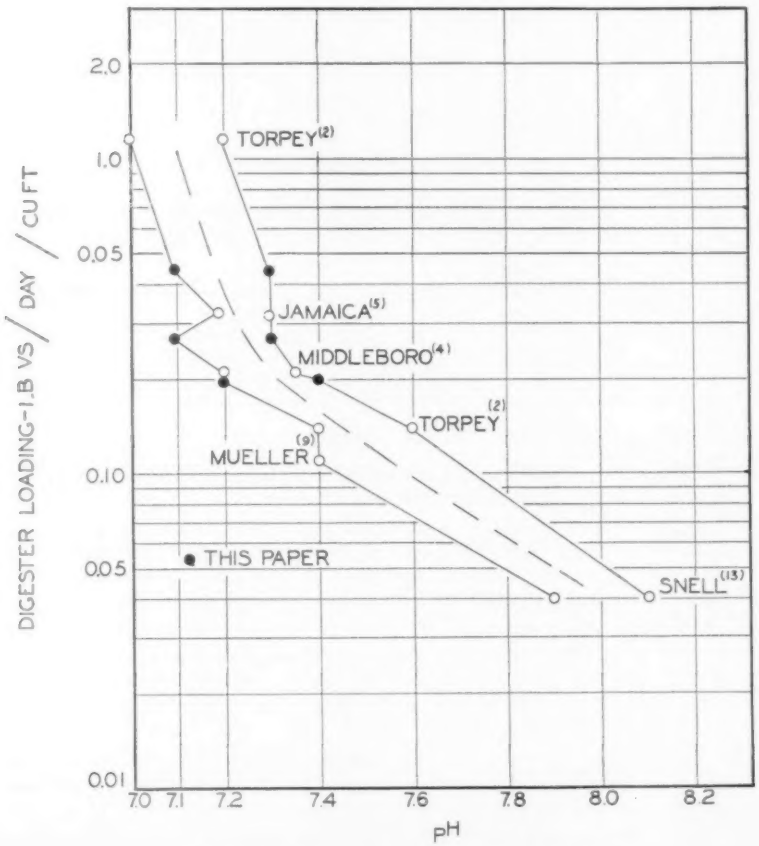

FIGURE 5.—Digester loading vs. operating pH.

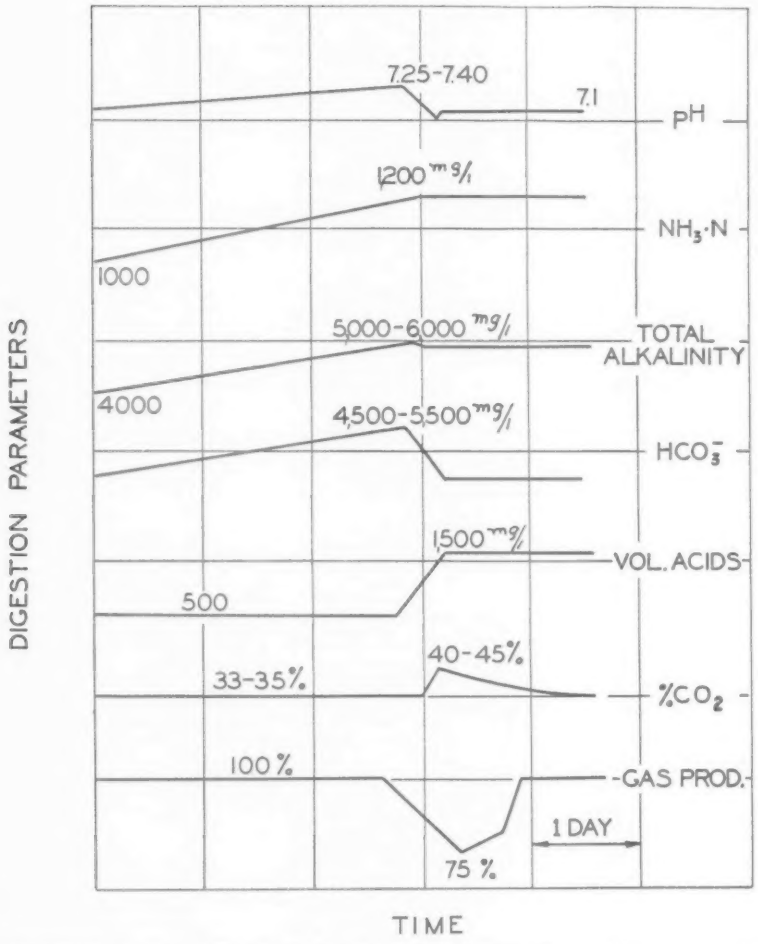

FIGURE 6.—Hypothetical partial pH—NH_3-N failure followed by recovery in a more favorable pH environment.

as the NH_3-N level exceeds 1,000 to 1,200 mg/l and the pH increases to 7.3 or 7.4. The excess volatile acids provide a natural suppression of the pH to a level more favorable to bacterial growth. This will not affect gas production, other than the amount of organic acids which were accumulated, until the acid level exceeds 2,500 to 3,000 mg/l as acetic acid. Figure 6 is a hypothetical example of the observed reactions that occur following an increase in NH_3-N beyond the critical level. These reactions occur in less than a day and are not always as clearly defined as the example.

The unfavorable pH causes a reduction in the metabolism rate of the volatile acids, whereas the hydrolytic enzymes remain unaffected over a wide pH range. This leads to an immediate buildup of volatile acids, which replace a portion of the bicarbonate alkalinity, causing an increase in CO_2 content of the gas and a decrease in the pH. After the decline in pH, normal gas

production resumed. If the ammonia level kept increasing, the reaction would re-occur until the volatile acids inhibited gas production.

The foregoing evidence indicates that high-rate digestion may operate in a very restricted range of pH. The pH, as controlled by the NH_3-N concentration, will regulate the equilibrium within the digester.

It cannot be definitely proved that the addition of HCl was the reason the two digesters recovered in Series B, because the organic load also was removed. This is also true for digester 4 in Series A. In each case the acid addition lowered the level of accumulated organic acid and seemingly hastened recovery. The effect of the hydrochloric acid would be as follows:

$$NH_4HCO_3 + HCl \longrightarrow NH_4Cl + H_2CO_3 \rightleftharpoons CO_2\uparrow + H_2O$$

$$H_2CO_3 + CH_3COO\cdot NH_4 \xrightarrow[\text{Bacteria}]{\text{Methane}} CH_4\uparrow + CO_2\uparrow + NH_4HCO_3 \quad \ldots\ldots (6)$$

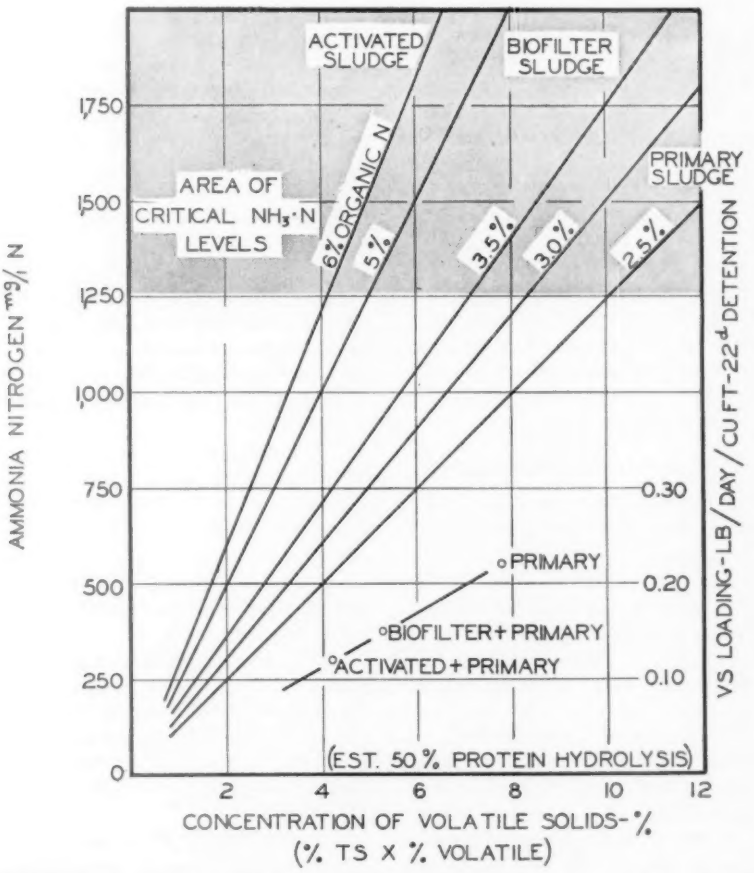

FIGURE 7.—Relative NH_3-N production from digesting various sludges at their maximum feasible concentration achieved by gravity thickening.

The immediate reaction of the HCl addition will be to drive the pH down. However, it will increase as the organic acids are reduced and replaced by NH_4HCO_3. Because a portion of the ammonia is tied up as NH_4Cl, the equilibrium pH will be lower.

Digester Foaming

It appears that foaming may occur under two different circumstances. First, foaming often occurs when the methane bacteria rapidly metabolize a high concentration of organic acids. Hence, the foaming results from the high biological activity. Other instances of persistent foaming are encountered where the volatile acid concentration is stable in the range of 500 to 2,000 mg/l. This type of foam condition does not seem related to a changing biological activity. "Grease" has received much attention, as foam solids may contain large proportions of this material, because grease is the lightest organic fraction present.

From the observations made during this study, it appears that the minute gas bubbles and inability to coalesce indicate that a change has occurred in the surface tension of the digester liquid. It is not apparent what would cause this change.

Full-Scale Considerations

The problem of excess NH_3–N will not occur where thickening by conventional settling methods is practiced, because the concentration of solids required to produce 1,250 mg/l of NH_3–N is difficult to obtain by settling. Primary sludge and mixed primary and biofilter or activated sludge can be feasibly thickened to 12-, 8-, and 6-per cent TS maximum concentration, respectively. Figure 7 shows the loading rate attained with these maximum concentrations when the detention is 22 days. If the normal content of organic nitrogen is present in the thickened domestic sludges, anaerobic digestion will proceed normally with NH_3–N concentrations less than 1,250 mg/l. Because the ammonia nitrogen is derived from the organic fraction, the volatile solids content is shown on the abscissa.

Any future increase in loading with higher feed solids will require consideration of possible neutralization of ammonia. One method mentioned is the use of HCl. Another possibility would be to artificially increase the percentage of CO_2 in the gas phase. This would set up an optimum pH equilibrium at higher alkalinities.

Summary and Conclusions

1. In two series of tests, laboratory-scale pilot digestion units were operated at and above the present high-rate loading zone. These digesters were fed concentrated solids which would produce alkalinities up to 6,000 mg/l. The digesters were fed twice daily and continuously mixed by stirrers.

2. The digesters failed at loadings of 0.20, 0.27, and 0.44 lb VS/day/cu ft. Failure was not connected with loading rate, but occurred when NH_3–N exceeded 1,250 mg/l. Either high solids or an artificial increase in the alkalinity by addition of NH_4HCO_3 resulted in failure of the digester by excess volatile acids.

3. Ammonium ion in the form of NH_4Cl was not toxic or inhibitory at a concentration of 1,800 mg/l N. As much as 5,000 mg/l of NH_3–N has been reported in digesters where the loading rate was low, but as the loading increased the allowable concentration was found to decrease.

4. There is a biochemical equilibrium within the digester between pH, NH_3–N, CO_2, and volatile acids which may be described by an empirical equation. The coefficients in this equation change, depending on the range of NH_3–N.

5. The optimum pH is about 7.1; the pH must approach this value if higher loadings are desired. A pH of 7.3 to 7.4 at a loading of 0.3 lb VS/day/cu ft

may be inhibitory until the digester accumulates enough volatile acids to neutralize the digester contents. Only the methane producers are inhibited while the volatile acid production remains normal.

6. The high pH problem is not present with certain types of thickening because the underflow solids cannot be sufficiently concentrated by settling. If sludge is to be concentrated further prior to digestion, neutralization by an acid source must be considered if equilibrium is to be maintained.

Acknowledgment

The author gratefully appreciates the help given by Chris Miele in the graphical presentation of the data in this paper.

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PLASTIC PIPE STANDARD

The second edition of the "Commercial Standard for Plastic Drain and Sewer Pipe and Fittings," CS228-61 has been announced and supersedes all previous editions.

The printed edition of the revised standard will become available from the Government Printing Office in the near future and copies will be distributed to each recorded acceptor. Additional copies will be available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

CLEANING DIGESTERS AT NILES, MICHIGAN

Ralph A. Garno

The Niles Sewage Treatment Plant has two fixed cover digesters. Each digester has the operating capacity of 321,000 gallons. They are 55 ft in diameter and 27 ft deep. They are designated as the North and South digesters on the operating report sheets. Three supernatant overflow pipes, each drawing from a different depth, are located in a common concrete receiving box, on the top side of each digester. These supernatant overflow pipes have removable rings for the best selection of supernatant, and their receiving box drains into the influent wet well.

Both of the digesters are used as primary digesters and are heated by hot water circulating through 3 in. diameter steel heating coils. The source of heat for the hot water is provided by either the oil boiler, sewage gas boiler, and/or the gas engine jacket water passing through a heat exchanger. The optimum digester sludge temperature is 85°F to 90°F for proper, efficient digestion. Raw sludge pumping is alternated to each digester every three days.

Scale Problem

When the internal heating coils in the digesters build up with a hard scale on their outside surface, their heat transfer value is reduced in direct proportion to the amount of scale present.

The sludge temperatures started declining in Oct. 1957, and could not be increased, as the heating water entering the coils was near the critical 140°F. However, the weather delayed the cleaning project.

Cleaning Preparations

On May 8, 1958, the plant operating staff started this project, working on a 24 hr a day, seven days a week basis, until both of the digesters were cleaned and back in operation. Raw sludge was not pumped the previous week to the North digester, as it was to be cleaned first, but it was circulated continuously during this time.

The main gas-line valve was closed next on the North digester. Then using extreme care to avoid sparks the gas relief valve on the gas dome was opened. When the gas pressure was relieved, the gas dome and sampling flanges were removed. The gas collection pipe inside the gas dome was then plugged with rags to prevent rain from entering. Then the three supernatant overflow pipes were sealed off by placing a 2 in. by 6 in. board over the top of them with concrete blocks on the board for weight. Raw sewage was then pumped by the raw sludge pump into the digester until the liquid was about to run out of the two digester entry doors. The digester contents were circulated during this time. The gas present in the normal gas collection area was displaced by raising the liquid level by this means.

The digester contents were pumped to the drying beds with a digested sludge piston pump. Both of the digester entry doors were opened for cross ventilation at this time. A garden hose with a high pressure nozzle was

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This paper was given at the Michigan Sewage and Industrial Wastes Meeting, May 1960.

lowered through the gas dome into the sludge. This surging water action kept the sludge in a homogeneous mass around the suction end of the sludge pipe in the digester.

Cleaning Method

The electric department furnished two lineman's harnesses and belts that were used while working inside the digester. A heavy rope was secured to the rung ladder and on each harness.

When the liquid level in the digester reached the upper section of the heating coils, a 14 ft ladder was lowered through the entry door and swung out to the coils. Boards were then placed on this ladder for a walkway, and ropes secured on both sides of the ladder as safety railings. A fire hose was then lowered and tied securely with rope to the heating coils, so that the nozzle could be directed without the danger of the hose whipping the man off the ladder platform. The heavy sludge deposits were broken up and washed toward the center of the digester. The garden hose, with the high pressure nozzle, kept the area around the suction end of the pipe free of hard sludge. The digester was pumped empty by this method, except for approximately 2 cu yd of sand that remained in the cone.

Debris Removal

By pounding with a hammer the heating coils were cleaned of approximately ¼ in. scale coating. An old file was used to tap the scale off the cast iron elbows on the heating coils. The sand and scale debris was removed with a shovel and lifted in a bucket through the entry door.

The North digester was filled with 100,000 gal of raw sewage May 31. On June 1, the gas line was shut off on the South digester and the same procedure was followed.

When this digester was pumped nearly full of liquid, approximately 180,000 gal of digested sludge were transferred to the North digester for seed. The remaining contents were pumped to the drying beds and lagoon.

A special flange was installed on the outer drying bed sludge valve and this was connected to 200 ft of 4 in. diameter aluminum irrigation piping that was purchased for this purpose. This setup permitted pumping either to a swamp lagoon next to the drying beds, or to a tank truck.

When the second digester was completely empty, except for approximately a cubic yard of sand, inspection disclosed that one of the concrete supports for the suction pipe was broken. Further inspection disclosed that this support was not reinforced and was poured on top of the digester floor. This support was replaced and the heavy deposit of scale on the coils was hammered off. A new black metal union was installed on one of the lower heating coils to provide a means of flushing out the mineral deposits inside the coils.

On June 17, the digester was filled with approximately 100,000 gal of raw sewage. Then approximately 90,000 gal of digested sludge were transferred from the North digester for seed.

Return to Operation

On June 19 both digesters were filled to operating level with raw sewage. The rag plugs were taken out of the gas collection lines and the gas dome and sampling flanges secured on both digesters. As both digesters were placed back in normal service all the gas was bypassed to the atmosphere through the water-sealed, gas-pressure relief tank. The CO_2 content was high and the methane composition too low to be utilized.

The oil boiler was operated to raise the liquid temperature to 90°F. Each digester was circulated for 8 hr per day. The raw sludge was added to the digesters on a 3-day alternate basis.

The gas bypass line was closed on July 24, the main gas line opened, and the gas used in the gas boiler and gas engine. Both digesters had a rapid, normal recovery.

Summary

Nearly two years after cleaning it is possible to maintain a 10°F differential between the heating water temperature entering the digesters and the digester contents.

Cleaning the digesters requires careful planning and is one of the most hazardous operations that is performed at a sewage treatment plant.

Digesters need cleaning for a variety of reasons and almost always personnel must enter them. Precautions against asphyxiation and explosions must be taken throughout the entire process. This can be accomplished by careful planning and careful utilization of the plan.

GRADUATE TRAINING RECOMMENDATIONS

In the 1960 Report of the Board of Trustees of the American Sanitary Engineering Inter-Society Board, Inc. are contained several recommendations for graduate training programs. These were the result of a three-day conference on the graduate education of sanitary engineers held jointly by the ASEIB, Harvard University, the Massachusetts Institute of Technology, and the National Science Foundation. Among the recommendations were:

1. The Engineers' Council for Professional Development should be requested to act favorably on the recommendation of the ASEIB that graduate programs in sanitary engineering be covered by an accreditation program of ECPD.

2. The ASEIB through its Committee on Education should study the desirability of collaboration among schools having programs in fields of engineering related to environmental health.

3. The length of time for graduate instruction leading to the first graduate degree in engineering relating to environmental health should be one calendar year rather than an academic year.

4. The graduate instruction leading to the Master's or higher degree should include core courses in chemistry, microbiology, radiological hygiene, statistics, and epidemiology.

5. The ASEIB working with appropriate representatives of the other engineering groups active in sanitary engineering should attempt to reconcile differences in the use of terminology in referring to the sanitary engineer with the objective of reaching agreement on a single title satisfactory to all.

TIPS AND QUIPS

Clam Harvesting Prohibited

The States of New York and New Jersey prohibited the harvesting of clams in the Raritan Bay area on May 1, 1961.

This action was taken when it appeared that there was an association between hepatitis and the eating of raw clams taken from the Bay which receives water from the heavily polluted Raritan and Arthurkill Rivers.

Dr. Luther L. Terry, Surgeon General of the Public Health Service, has called a conference for all concerned to be held on Aug. 22 and 23.

In making the announcement, Dr. Terry said:

"It ought to be clearly understood that the purpose of the conference is to deal with the broad problem of water pollution in this area, not solely with the effects of water pollution on clams. . . ."

If suitable pollution abatement is not undertaken after the first conference, federal procedures call for a public hearing before a specially-constituted board, and possible further enforcement action by the Department of Justice.

Award to Senator

Senator Robert S. Kerr has been given the "Award of Merit" by the American Association for Conservation for his book "Land, Wood, and Water."

He calls for quick decisive measures to relieve the "dangerous water shortage facing the nation." His recommendations were echoed in President Kennedy's Special Message to Congress in his statement "Our entire society rests upon, and is dependent upon, our water, our land, our forests, and our minerals."

Water Use Improvement

Industrial-process engineers have reduced water requirements:

	Gallons of water needed per ton produced	
	Formerly	Today
Steel	55,000	3,000
Paper pulp	45,000	9,000
Newsprint	26,000	6,000
Cannery products	2,500	1,200

John W. Cramer,
President-Elect, AWWA

Fooled Firemen

In St. Louis, Mo., firemen directed streams of water on the motor of a parked car, the center of a pall of smoke, but it had no effect. Investigation disclosed the car had been parked over a steaming manhole.

It's All in the State of Mind

If you think you're beaten, you are;
If you think you dare not, you don't;
If you think you'd like to win, but you can't;
It's almost a "cinch" you won't;

If you think you'll lose, you've lost;
For out in the world you'll find
Success begins with a fellow's will—
It's all in the state of mind.
Think big, and your deeds will grow,
Think small and you fall behind,
Think that you can, and you will;
It's all in the state of mind.

If you think you are outclassed, you are;
You've got to think high to rise;
You've got to be sure of yourself before
You can ever win a prize.

Life's battle doesn't always go
To the stronger or faster man;
But sooner or later; the man who wins
Is the fellow who thinks he can.

Author Unknown

Mosquito Control on Lagoons

We want you to know that the growing trend toward lagoons for sewage treatment has not been unnoticed by others.

The following resolution was transmitted to the Federation by William E. Bickley, President of the American Mosquito Control Association, Inc. Mr. Bickley's address is Department of Entomology, University of Maryland, College Park, Md.

RESOLUTION PASSED AT ANNUAL MEETING OF AMERICAN MOSQUITO CONTROL ASSOCIATION

Anaheim, California
February 2, 1961

WHEREAS, there is a steady increase in the number of oxidation lagoons for sewage treatment in many parts of the United States,

AND WHEREAS these lagoons are potentially and actually sources of mosquitoes,

THEREFORE BE IT RESOLVED that the American Mosquito Control Association express its concern over the necessity of proper construction and maintenance of these lagoons,

AND BE IT FURTHER RESOLVED that the Association encourage research to find methods for alleviation of mosquito problems in these lagoons,

AND BE IT FURTHER RESOLVED that copies of this resolution be sent to state health officers in each of the fifty states, and to the Secretary of the Water Pollution Control Federation.

We would be pleased to receive copies of letters written to Mr. Bickley or would like to have first-hand comments.

Oil Pollution

The Indiana Water Pollution Control Association reports that Luther Woodward, Superintendent of the Mount Vernon sewage treatment plant, struck oil on March 22.

It all began when operator Victor Hessler checked the primary settling tanks and noticed a film of oil collecting on the surface of the liquid.

The sewer maintenance crew was rushed to the oil terminal in town and began checking nearby manholes. No evidence of oil was found in the collection system.

Two days later it was discovered that the oil was entering the plant influent from the sludge drying bed drain. The pipe line terminal just west of the plant was called and the two industries drilled test holes and located a break in a diesel fuel line. The oil was floating on the ground water and seeping into the drain line without coming to the surface.

The break was repaired, a ditch dug along the property line, the oil allowed to collect in the ditch for pumping into tank trucks, and the remaining film and seepage set on fire.

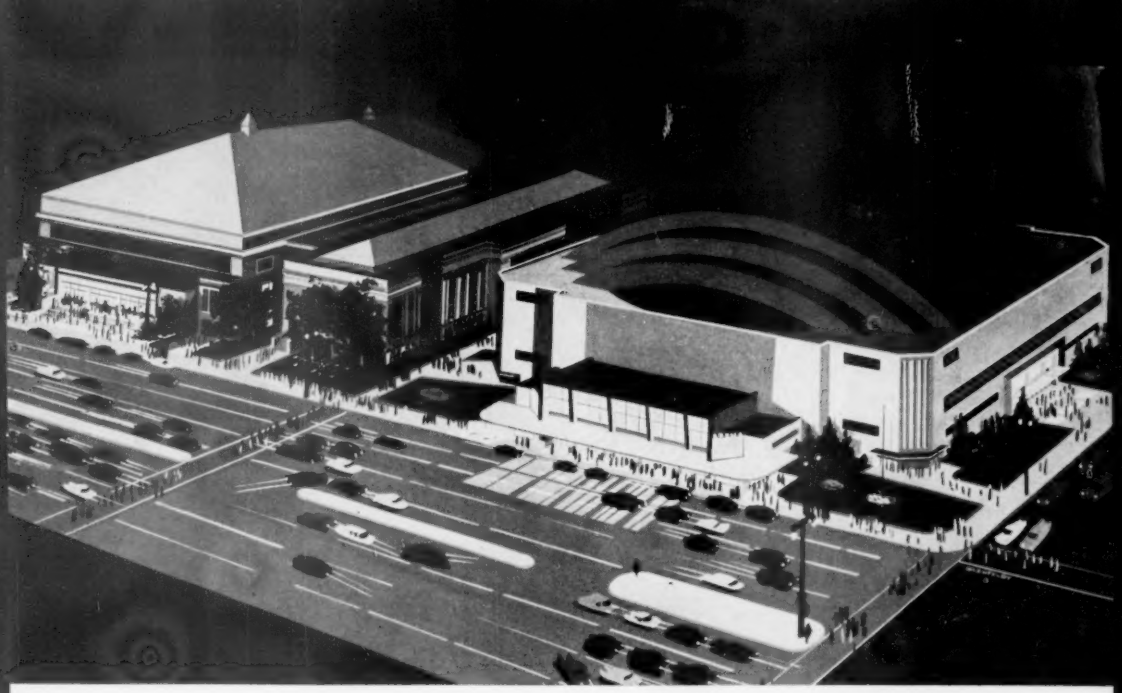
The plant was cleaned thoroughly and returned to normal operation.

Sewage Treatment Analysis

If sewage were discharged without treatment, it would be equivalent to sending a 2,000-ton train of water to transport a single ton of organic solids, and then throwing the train away after making only one trip.

P. H. McGauhey

Any man can start in the direction of better living from the spot on which he is standing now.



MILWAUKEE AUDITORIUM-ARENA

34th Annual Meeting

WATER POLLUTION CONTROL FEDERATION

HOST ASSOCIATION — CENTRAL STATES SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

HOTEL SCHROEDER AUDITORIUM-ARENA

Milwaukee, Wisconsin *October 8-12, 1961*

MEETING PROGRAM

THIRTY-FOURTH ANNUAL MEETING

Hotel Schroeder, Milwaukee, Wis.

Technical Sessions and Exhibits—Auditorium

October 8–12, 1961

HOST ASSOCIATION—CENTRAL STATES SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

THE OFFICIAL PROGRAM

Registration Sunday, 1–5; Monday–Wednesday, 8:30–4:30.
Auditorium

Inspection of Exhibits—Sunday, 1–5; Monday–Wednesday, 9–5; Thursday, 9–12.
Auditorium

SUNDAY, OCTOBER 8

Afternoon

Early Registration—Auditorium

MONDAY, OCTOBER 9

Morning

Registration—Auditorium

Call to Order
President Ray E. Lawrence

Invocation

Address of Welcome—J. F. Friedrick, Chairman, Sewerage Commission of the City of Milwaukee

Reports of Federation Officers

The Milwaukee Story
Ray D. Leary, Chief Engineer, General Manager, Milwaukee Sewerage Commission, Milwaukee, Wis.

Afternoon—Water Pollution Roundup

What We Know About Wastes and Pollution
Gordon M. Fair, Professor of Sanitary Engineering, Harvard University, Cambridge, Mass.

What We Need to Know About Wastes and Pollution
Thomas J. Powers, Consulting Director, Dow Industrial Service, Dow Chemical Company, Cleveland, Ohio

Getting Needed Information about Wastes and Pollution
Sidney A. Berkowitz, Assistant Director, Bureau of Sanitary Engineering, Florida State Board of Health, Jacksonville, Fla.

TUESDAY, OCTOBER 10

Morning—Concurrent Sessions

SESSION A—LARGE SYSTEM DESIGN

Design of Hamilton, Ontario, Sewer System and Sewage Treatment Works
D. B. Redfern, Partner, Proctor and Redfern, Consulting Engineers, Toronto, Ontario

Large Sewer System Design
G. A. Horstkotte, Jr., Manager, Central Contra Costa Sanitary District, Walnut Creek, Calif.

Planning, Development, and Administration of Intercommunity Sewerage and Sewage Treatment Systems in a Metropolitan Complex

Part I. The Wayne County, Michigan, Situation
George R. Bingham, Director, Wayne County Department of Public Works, Detroit, Mich.

Part II. The Oakland County, Michigan, Situation
R. J. Alexander, Director, Oakland County Department of Public Works, Pontiac, Mich.

SESSION B—INDUSTRIAL WASTES FORUM

SURFACE AND SUBSURFACE DISPOSAL OF INDUSTRIAL WASTES

Spray Irrigation as a Means of Industrial Waste Disposal
Howard G. Luley, Sanitary Engineer, H. J. Heinz Company, Pittsburgh, Pa.

Ridge and Furrow Irrigation for Industrial Waste Disposal
Francis H. Schraufnagel, Sanitary Engineer, Committee on Water Pollution, State Board of Health, Madison, Wis.

Disposal of High Organic Content Wastes on Land
Ralph H. Scott, Public Health Engineer, Wisconsin State Committee on Water Pollution, Madison, Wis.

Fundamentals of Underground Disposal of Industrial Wastes
Charles W. Querio, Assistant Superintendent, Well Department, Dow Chemical Company, Midland, Mich.

Noon

FEDERATION LUNCHEON

Address
The Honorable Frank E. Moss, U. S. Senate (Utah)

Afternoon

INSPECTION TRIP

Wastewater Treatment Plant of the Sewerage Commission of Milwaukee

INDUSTRIAL WASTES SESSION

Preventive Measures Get Results in Solvay's Waste Abatement Program

W. L. Leucht, Chemical Engineer; P. T. McNalley, Plant Engineer, Solvay Process Division, Allied Chemical Corporation, Syracuse, N. Y.; and Irving Grossman, Senior Sanitary Engineer, N. Y. State Department of Health, Syracuse, N. Y.

Anaerobic Digestion of Textile Desizing Wastes

Theodore Jaffe, U. S. Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio

The Relation Between Phenol Concentrations and Medicinal Odors in Water

Max Katz, Technologist, and C. J. Bradac, Associate Technologist, U. S. Steel Corporation, Applied Research Laboratory, Monroeville, Pa.

WEDNESDAY, OCTOBER 11

Morning—Concurrent Sessions

SESSION A—INDUSTRY DAY

Computer Analysis of Data Collected in a Cooperative State and Industry Study

Robert O. Sylvester, Professor, Sanitary Engineering, Dale A. Carlson, Associate Professor, Civil Engineering, University of Washington, Seattle, Wash.; Donald J. Benson, Associate Sanitary Engineer, Oregon State Sanitary Authority, Portland, Ore.; Wallace W. Bergerson, Director, Washington Pollution Control Commission, Olympia, Wash.; and Vinton W. Bacon, Executive Secretary, Northwest Pulp and Paper Association, Tacoma, Wash.

Present Status of Commercial Scale Operation of Stream Reaeration Facilities

Averill J. Wiley, Technical Director, Bernard F. Lueck, Chief Chemist, Sulphite Pulp Manufacturers Research League, Appleton, Wis.; Ralph H. Scott, Public Health Engineer, and Theodore F. Wisniewski, Director, Wisconsin State Committee on Water Pollution, Madison, Wis.

Waste Abatement Progress in the Pulp and Paper Industry

Harry W. Gehm, Technical Advisor, National Council for Stream Improvement, Inc., New York

A Solution to Industrial Waste Disposal—Tailor-Made Answers Not a Panacea

Richard Billings, Administrative Assistant to Vice-President of Mfg., Consumer Products Division, Kimberly-Clark Corporation, Neenah, Wis.

SESSION B—THE GREAT LAKES RESOURCE

Physiography of the Lakes

Norman F. Billings, Chief, Hydrology Division, Michigan Water Resources Commission, Lansing, Mich.

Water Uses

G. A. Rohlich, Director, Hydraulic and Sanitary Laboratory, College of Engineering, University of Wisconsin, Madison, Wis.

Current and Future Problems and Needs to Be Served

Albert E. Berry, General Manager, Ontario Water Resources Commission, Toronto, Ontario

Significant Aspects of the Great Lakes–Illinois River Basins Project

H. W. Poston, Regional Program Director, Water Supply and Pollution Control, U. S. Public Health Service, Chicago, Ill.; and Wm. Q. Kehr, Project Director, Great Lakes–Illinois River Basins Project, Chicago, Ill.

Noon

INDUSTRY LUNCHEON

Address

John G. Strange, President, The Institute of Paper Chemistry, Appleton, Wis.

Afternoon—Concurrent Sessions

SESSION A—INDUSTRY DAY

Mead's Experience with Plastic Trickling Filter Media at Rome, Georgia

Virgil A. Minch, Associate Director, Corporation Technical Service, John T. Egan, Technical Consultant, Mead Corporation, Chillicothe, Ohio; and McDewain Sandlin, Chief Chemist, Rome Kraft Company, Rome, Ga.

Discussion

William H. Weir, Director, Water Quality Service, Georgia Department of Health, Atlanta, Ga.

Biological Treatment of Fine Chemical Plant Wastes

W. R. Horne, Department Head, U. S. Rinaca, Sr. Process Supervisor, Robert L. St. Clair, Sr. Mechanical Engineer, and Henry E. Hartman, Jr. Process Supervisor, Merck and Company, Inc., Elkton, Va.

Discussion

David Schwarz, Chemical Engineer, Abbott Laboratories, North Chicago, Ill.

Presenting a Waste Control Program to Management

Charles L. Sercu, Manager, Waste Control Utilization, Dow Chemical Company, Midland, Mich.

SESSION B—MAINTENANCE FORUMS

Problems with Pump Operation and Maintenance

R. C. Thayer, Director, Operations, Hampton Roads Sanitary Commission, Hampton Roads, Va.

Chlorination Operation and Maintenance Problems

A. A. Thomas, Senior Associate, Metcalf and Eddy, Boston, Mass.

Sewer Maintenance at La Crosse, Wisconsin

Carl Wahlstrom, Superintendent, Sewage Treatment Plant, Board of Public Works, La Crosse, Wis.

SESSION C—SLUDGE, RESEARCH NEEDS, AND COLLECTION

New Developments in the Zimmermann Process

F. J. Zimmermann, Vice-President, Sterling Drug Inc., New York; and Neal Seegert, Vice-President, Zimpro Division of Sterling Drug Company, Rothschild, Wis.

Water Pollution Control Research—Need for Renewed Effort

Frank A. Butrico, Chief, Office of Resources Development, U. S. Public Health Service, Washington, D. C.

Garbage, Detergents, and Sewers

Francis R. Bowerman, Assistant Chief Engineer, Los Angeles County Sanitation District, Los Angeles, Calif.

Evening

ANNUAL FEDERATION AWARDS DINNER AND DANCE

THURSDAY, OCTOBER 12

Breakfast—Laboratory Scientists

Research on Advanced Waste Treatment

Gordon E. McCallum, Chief, Division of Water Supply and Pollution Control, U. S. Public Health Service, Washington, D. C.; and Francis M. Middleton, Chief, Advanced Treatment Research, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio

Morning—Concurrent Sessions

SESSION A—RESEARCH SYMPOSIUM

Organic Composition of a Domestic Sewage

Joseph V. Hunter, Lecturer, Department of Sanitation, and H. Heukelekian, Chairman, Department of Sanitation, Rutgers University, New Brunswick, N. J.

Composition of Volatile Solids Accumulating in an Activated Sludge System

Donald R. Washington, Asst. Professor, Environmental Engineering, Rensselaer Polytechnic Institute, Troy, N. Y.; and James M. Symons, Asst. Professor, Sanitary Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

Arginine, Cystine, and Glycine Utilization by Activated Sludge

Dale A. Carlson, Associate Professor, Civil Engineering, University of Washington, Seattle, Wash.; and Lawrence B. Polkowski, Professor, Sanitary Engineering, State University of Iowa, Iowa City, Iowa

The Chromatographic Assay of Extracellular Products of Algal Metabolism

Robert C. Merz, Professor, Civil Engineering, University of Southern California, Los Angeles, Calif.; John R. Klima, Department of Biology, University of Washington, Seattle, Wash.; and Raymond G. Zehnpfennig, Research Associate, Verdugo Laboratories, Tujunga, Calif.

SESSION B—OPERATOR'S FORUM

Short Cuts and Improvements in Laboratory Procedures

W. D. Hatfield, Consultant, Decatur, Ill.

Sludge Drying Lagoons

N. S. Bubbis, Director, Waste and Waterworks Division, Metropolitan Corporation of Greater Winnipeg, Winnipeg, Manitoba

Stirring Digesters with Gas

Hugh A. Schreiber, Superintendent, D. C. Sewage Treatment Plant, Washington, D. C.

Mechanical Nozzles for Aeration Tanks

Charles E. Hughes, Superintendent, City Sanitary District, Decatur, Ill.

Afternoon—Concurrent Sessions

SESSION A—RESEARCH SYMPOSIUM

Analysis of the Economics of Sewage Treatment

John A. Logan, Chairman, Civil Engineering Department, Northwestern University, Evanston, Ill.; W. D. Hatfield, Consultant, Decatur, Ill.; George S. Russell, Chairman of the Board, Russell and Axon, St. Louis, Mo.; and Water R. Lynn, Technological Institute, Northwestern University, Evanston, Ill.

Enterovirus Distribution in Sewage During the 1959 Des Moines Poliomyelitis Epidemic

John S. Wiley, Biophysics Section, Technical Development Laboratories; Tom D. Y. Chin, Assistant Chief, Epidemiology Branch; Clifton R. Gravelle, Epidemiology Branch; Communicable Disease Center, U. S. Public Health Service, Savannah, Ga., Kansas City, Kans., and Kansas City, Kans., respectively; and Sherry Robinson, Chief, Environmental Sanitation Sect., Des Moines-Polk County Health Dept., Des Moines, Iowa

Ion-Exchange for High-Order Decontamination of Radioactive Wastes

Warren J. Kaufman, Asst. Professor, Sanitary Engineering, University of California, Berkeley, Calif.; Arliss D. Ray, Associate Professor, School of Engineering, Vanderbilt University, Nashville, Tenn.; and Marvin Goldman, Associate Research Radiologist, University of California, Davis, Calif.

Controlling Operation to Minimize Activated Sludge Effluent Nitrogen

F. J. Ludzack, Chemist, and M. B. Ettinger, Chief, Chemistry and Physics, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio

SESSION B—PUBLIC RELATIONS

Annual Reports

Carl J. Bernhardt, Regional Director, Public Health Engineering, N. Y. State Health Department, Buffalo, N. Y.

American Water Works Association Advancement Program

Eric F. Johnson, Director of Advancement, American Water Works Association, New York

Accomplishments of Manufacturers in Public Relations

Robert F. Orth, Senior Vice-President, General Manager, Pipe Division, Johns-Manville Corporation, New York

Public Relations Program of the Water Pollution Control Federation

Philip A. Ridgely, Manager, Advertising and Public Relations, Water Pollution Control Federation, Washington, D. C.

TECHNICAL PROGRAM COMMENTS

The technical program, enlarged again this year, includes 14 formal sessions with 49 papers, 2 prepared discussions, and 2 luncheon addresses.

The Program Committee, under the chairmanship of George E. Symons, has arranged a timely and well-rounded technical program that will interest members engaged in all fields of water pollution control.

Industrial wastewaters are again spotlighted on INDUSTRY DAY in addition to the industry papers presented throughout the entire program. The Industry Luncheon address will be by John G. Strange, President of the Institute of Paper Chemistry.

The technical sessions have been scheduled to allow time for short breaks between papers and time to reach the next session without rushing. Admission to technical sessions is by Federation badge only.

All technical sessions will be held in the Auditorium. The luncheons will be at the Schroeder.

FESTIVITIES

The Local Host Committee has arranged for enjoyable evening entertainments after the technical sessions. These are delightful programs that make the most of the best in Milwaukee.

Monday night will feature the Holiday Folk Fair Dancers in their famous renditions of European folk dances. This will be a colorful and high-stepping evening with the dancers dressed in authentic "old world" costumes.

Tuesday evening is free from formal arrangements and the Local Host Committee will assist in planning the evening for either individuals or small groups. There is plenty to enjoy in Milwaukee and this, coupled with the friendly atmosphere, should promote a wonderful time.

The Federation Awards Dinner will be held on Wednesday evening in the Arena. Here will be the annual presentation of awards and honors, and the formal introduction of the new Federation officers. This speechless dinner, with dancing later, is the social highlight of the meeting.

Music, ranging from fox trots to polkas, will be by Steven Swedish's Orchestra. Either formal or street dress is suitable.

The Conference of State Sanitary Engineers has scheduled, in addition to the official functions, a breakfast for Wednesday morning. Also, the Wisconsin Sewage Works operators will meet Wednesday afternoon.

The exhibit hall is open daily to registered members and many enjoyable and worthwhile hours may be spent in viewing the latest equipment and methods used in wastewater collection and treatment. Members may also take advantage of unscheduled tours that are provided by local industries.

Wear your identification, as admission to all technical sessions and exhibits is by badge only.

LADIES' ENTERTAINMENT PROGRAM

The October meeting in this locale is fortuitous as Milwaukee is an autumn paradise. The weather is cool with clear days enhancing the colorful changing of the leaves. Shopping and informal tours will be enjoyed in the invigorating air.

Monday's fashion show will serve as a "get acquainted" tea for the wives and as a starting point for new-found friends to begin their shopping ventures.

A delightful lunch will be served Tuesday at the famous Chalet on the

Lake. This restaurant, set on the rugged, wooded shoreline, overlooking blue Lake Michigan, offers excellent food. The leisurely lunch in such a restful atmosphere, complemented by a chauffered drive through Milwaukee's finest residential sections, will be a pleasant change from the busy convention. It will be a long-remembered event.

Wednesday brunch, with entertainment, at the Hotel Schroeder will give all a chance to compare purchases and discuss the sights that have been enjoyed. The rest of the day may be spent in additional side trips or returning to the best enjoyed stores.

Ladies are welcome at the exhibit hall throughout the meeting. This is an excellent opportunity to become more familiar with the equipment your husband deals with.

TECHNICAL FIELD TRIP

The Tuesday afternoon field trip through the Milwaukee Sewage Treatment Plant on Jones Island is one of the main features of the meeting. This plant, built in 1925 with an initial capacity of 80 mgd, was a pioneer operation using the activated sludge process. The first major addition in 1935 added 70 mgd to the capacity, and the last expansion to a total capacity of 200 mgd was completed in 1952.

The activated sludge plant consists of coarse and fine screens on the influent line, primary and secondary aeration tanks, and sludge collection facilities. The plant operation is 95-per cent efficient in the removal of both SS and BOD, with the final effluent discharged into the confluence of three rivers. The waste sludge is conditioned with ferric chloride prior to vacuum filtration and final processing into fertilizer.

This fertilizer, sold worldwide under the trade name of "Milorganite," is an organic granular material containing approximately six per cent nitrogen, four per cent phosphate, and one half of one per cent potash. Approximately 70,000 tons of Milorganite are produced annually.

This plant has been the subject of many technical papers because of the interesting innovations in sewage treatment used. The unique commercial application of the sludge disposal problem is well worth viewing by designers, operators, and managers of wastewater utilities, in addition to the opportunity to inspect a well-planned, well-executed, and large-scale operation of sewage treatment.

The importance of this trip precludes the necessity for concurrent inspections that are usually available at the annual meetings as it will appeal to all facets of the Water Pollution Control Federation.

EXHIBITS

Exhibits by members of the Water and Sewage Works Manufacturers Association will be on display daily beginning Sunday afternoon.

The latest innovations in the collection and treatment of wastewater will be shown and time spent in the exhibit hall will be well worthwhile.

The following companies have already engaged space and will present the finest available display of wastewater equipment:

Airkem, Inc.
American City Magazine
American Pipe & Construction Company, Amercoat Division
American Well Works
Armco Drainage & Metal Products Inc.
B-I-F Industries, Inc.
Bird Machine Company
Ralph B. Carter Company
Chain Belt Company
Chicago Pump Company

Combustion Engineering, Inc., Raymond Division
DeZurik Corporation
Reuben H. Donnelley Corporation (Wastes Engineering Magazine)
Dorr-Oliver Incorporated
Dow Industrial Service
Eimco Corporation
Engineering News-Record Magazine
Fischer & Porter Company
Fisher Scientific Company
Flexible Incorporated
Foxboro Company
Gorman-Rupp Company
Hardinge Company, Inc.
Inertol Company, Inc.
Infilco Incorporated
Inspectoline, Inc.
Jeffrey Manufacturing Company
Johns-Manville
Keasbey & Mattison Company
Komline-Sanderson Engineering Corporation
Lakeside Engineering Corporation
Link-Belt Company
Lock Joint Pipe Company
Marlow Pumps, Division of Bell & Gossett Company
Minneapolis-Honeywell Regulator Company
Nichols Engineering & Research Corporation
Pacific Flush Tank Company
Penn Meter Company, Penn Instruments Division
Pfaudler Permutit Incorporated, Simplex Valve and Meter Division-Permutit Division
Public Works Magazine
Rockwell Manufacturing Company
Roots-Connersville Blower, Division of Dresser Industries, Inc.
Scranton Publishing Company, Inc. (Water and Sewage Works Magazine)
A. O. Smith Corporation
Smith-Blair, Inc.
Smith & Loveless, Division-Union Tank Car Company
Stuart Corporation
Sutorbilt Corporation
Tex-Vit Manufacturing Company
W-K-M Division of ACF Industries, Inc.
Walker Process Equipment Inc.
Wallace & Tiernan Incorporated
Waukesha Motor Company
WEMCO, Division of Western Machinery Company
Worthington Corporation
Yeomans Brothers Company
Zimpro Division of Sterling Drug, Inc.

REGISTRATION INFORMATION

All members and their ladies will register at the Milwaukee Auditorium. Registration will begin Sunday, Oct. 8 at 1 PM and will continue until 5. Registration will be from 8:30 to 4:30 Monday through Wednesday.

The registration fee of $14 includes admission to the technical sessions, the Monday evening Dance Festival, and the Annual Awards Dinner and Dance. Separately, the registration fee for admittance to the technical sessions and exhibit hall is $8, and the Wednesday night Dinner and Dance is $6.

Individual tickets are available for the Federation Luncheon on Tuesday, the inspection trip, the Laboratory Scientists' Breakfast, the Industry Day Luncheon, and the Annual Awards Dinner and Dance.

The wives' entertainment fee of $14 includes all the ladies' events and the Federation Dinner and Dance. Separately, the costs are $8 for the entertainment and $6 for the Dinner and Dance.

PREREGISTRATION

For streamlined registration, preregister by returning the reservation card included in the convention news flyer. This will allow more time to meet old friends in the lobby because all the paper work will have been com-

pleted and standing in line will be limited to stepping up to the desk and receiving the badges and tickets.

Preregistration reservations must be received by Oct. 4 to assure processing, so mail them now. Checks may be dated as late as Oct. 12 if you wish. None will be negotiated prior to then and they will be returned if you are unable to attend because of last minute plan changes.

HOTEL ARRANGEMENTS

The Hotel Schroeder is headquarters, but once again members have a choice of hotels that includes the Schroeder, the Wisconsin, the Plankinton, the Milwaukee Inn, and the Motel Continental. The locations and prices are given in the preconvention flyer mailed to each member. Reservation requests should be made as soon as possible using the hotel reservation card included in the preconvention flyer.

A housing bureau will handle the requests and will do everything possible to provide suitable accommodations among the five hotels.

All reservations must be received by October 4.

MILWAUKEE ARRANGEMENTS COMMITTEE

The Local Arrangements Committee with William N. Konrad as Chairman and Lloyd D. Knapp as Assistant Chairman have done an excellent job of leading the group in planning a wonderful time for Federation members attending the meeting.

The various Local Arrangements sub-committees are staffed by the following Federation members:

Finance: Raymond D. Leary, Chairman; Lawrence A. Ernest and A. Carlton Lind.

Inspection Trip: Lester C. Schier, Chairman; James Brower, Bruno J. Hartman, William Landsiedel, Chris Potos, and Anthony Geinopolos.

Entertainment: William Sivyer, Chairman; Leroy J. Beckman, J. A. Klein, David J. Coughlin, and H. K. Brill.

Events: B. Victor Pfeiffer, Chairman; Paul Thayer, John H. Mielke, Robert W. Frazier, Rodney W. Vanden Noven, and E. J. Beatty.

Registration: Fred O. Sullivan, Chairman; Gerald W. Lawton, Paul Knopp, Stan Johnson, Leonard A. Montie, William O. White, Theodore F. Wisniewski, M. R. Stiles, and M. Starr Nichols.

Local Host: Thomas T. Hay, Chairman; O. J. Muegge, Gerard A. Rohlich, Herbert O. Lord, William H. Plautz, Wayne Johnson, Frank Vilen, Lawrence B. Polkowski, John Mancini, William J. Katz, and Robert T. Steindorf.

Ladies Entertainment: Mrs. William Sivyer, Chairman; Mrs. William N. Konrad, Mrs. B. Victor Pfeiffer, Mrs. Thomas T. Hay, Mrs. Frank Vilen, Mrs. Lloyd D. Knapp, Mrs. Raymond D. Leary, Mrs. Paul M. Thayer, Mrs. William J. Katz, Mrs. Robert T. Steindorf, and Mrs. A. Carlton Lind.

STATE AND INTERSTATE WATER POLLUTION CONTROL AGENCIES

STATE OR TERRITORY	AGENCY AND ADDRESS	OFFICIAL AND TITLE
Alabama	Water Improvement Commission * State Office Building Montgomery 4, Ala.	A. N. Beck Technical Secretary
Alaska	Division of Health * Alaska Department of Health and Welfare Alaska Office Building Juneau, Alaska	Edwin O. Wicks, M.D. Acting Director, Division of Health Amos J. Alter Chief, Section of Sanitation and Engineering
Arizona	State Department of Health * State Office Building Phoenix, Ariz.	Clarence G. Salsbury, M.D. Commissioner of Public Health George W. Marx Director and Chief Engineer Bureau of Sanitation
Arkansas	State Water Pollution Control Commission * 921 West Markham Little Rock, Ark.	Glen T. Kellogg Technical Secretary
California	State Dept. of Public Health Bureau of Sanitary Engineering 2151 Berkeley Way Berkeley 4, Calif.	E. A. Reinke Chief, Bureau of Sanitary Engineering
	State Water Pollution Control Board * Room 316, 1227 "O" Street Sacramento 14, Calif.	Paul R. Bonderson Executive Officer
Colorado	State Dept. of Public Health 414 State Office Building Denver 2, Colo.	William N. Gahr Director, Division of Sanitation
	State Dept. of Public Health * 4210 East 11th Avenue Denver 20, Colo.	R. L. Cleere, M.D. Director of Public Health
Connecticut	Water Resources Commission * State Office Building 165 Capitol Avenue Hartford 15, Conn.	William S. Wise Director
	State Department of Health State Office Building Hartford 15, Conn.	Frederick O. Almquist Chief, Sanitary Engineering Section

* Designated by the Public Health Service to receive Federal water pollution control grants.

Delaware	State Water Pollution Commission * State House Annex Governor's Avenue and Division St. Dover, Del.	Donald K. Harmeson Executive Officer
	Water Pollution Commission State Department of Health 526 N. Governor's Avenue Dover, Del.	A. J. Kaplovsky Supervising Engineer
District of Columbia	District of Columbia Department of Public Health * Washington 1, D. C.	William H. Cary, Jr. Chief, Food and Public Health Engineering
Florida	State Board of Health * 1217 Pearl Street Jacksonville 1, Fla.	Wilson T. Sowder, M.D. State Health Officer
	Bureau of Sanitary Engineering State Board of Health Box 210 Jacksonville 1, Fla.	David B. Lee Director
Georgia	Georgia Dept. of Public Health * State Office Building Atlanta 3, Ga.	John H. Venable, M.D. Director
	Environmental Health Services State Dept. of Public Health 12 Capitol Square, S.W. Atlanta 3, Ga.	Roy J. Boston Director
Guam	Department of Medical Services * Agana, Guam	Joseph Kovacs, M.D. Director
Hawaii	Hawaii Department of Health * Kapuaiwa Building P. O. Box 3378 Honolulu 1, Hawaii	Richard K. C. Lee, M.D. Director of Health
	Hawaii Department of Health P. O. Box 3378 Honolulu, Hawaii	B. J. McMorrow Director, Division of Sanitation
Idaho	Idaho Department of Health * State House Boise, Idaho	Terrill O. Carver, M.D. Administrator of Health
	State Department of Health 422 State House Boise, Idaho	Vaughn Anderson Chief, Engineering and Sanitation Section
Illinois	State Sanitary Water Board * State Office Building 400 South Spring Street Springfield, Ill.	C. W. Klassen Technical Secretary

* Designated by the Public Health Service to receive Federal water pollution control grants.

Indiana	Stream Pollution Control Board * State Board of Health 1330 West Michigan Street Indianapolis 7, Ind.	B. A. Poole Technical Secretary
Iowa	Division of Public Health Engineering * State Department of Health State Office Building Des Moines 19, Iowa	Paul J. Houser Director
Kansas	Division of Sanitation * State Board of Health 510 State Office Building Topeka, Kans.	Dwight F. Metzler Chief Engineer
Kentucky	Water Pollution Control Commission * State Department of Health Frankfort, Ky.	Ralph C. Pickard Director and Chief Engineer
Louisiana	Division of Public Health Engineering * State Board of Health P. O. Box 630 New Orleans 7, La.	John E. Trygg Director
	Stream Control Commission Box 9055, University Station Baton Rouge 3, La.	Kenneth E. Biglane Executive Secretary
Maine	Water Improvement Commission * c/o Dept. of Health and Welfare State House Augusta, Me.	Dean H. Fisher, M.D. Secretary
	Division of Sanitary Engineering State Dept. of Health and Welfare Augusta, Me.	E. W. Campbell Director
Maryland	State Department of Health * State Office Building 301 W. Preston Street Baltimore 1, Md.	Robert M. Brown Chief, Bureau of Environmental Hygiene
	Water Pollution Control Commission 2114 N. Charles Street Baltimore 18, Md.	Paul W. McKee Director
Massachusetts	Massachusetts Department of Public Health * 546 State House Boston 33, Mass.	Alfred L. Frechette, M.D. Commissioner of Public Health Worthen H. Taylor Director, Division of Sanitary Engineering

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Michigan	State Department of Health Division of Engineering Old DeWitt Road Lansing 4, Mich.	John E. Vogt Director, Division of Engineering
	Water Resources Commission * Station B—Reniger Building 200 Mill Street Lansing 13, Mich.	Milton P. Adams Executive Secretary
Minnesota	State Department of Health Division of Environmental Sanitation Campus, University of Minnesota Minneapolis 14, Minn.	F. L. Woodward Director, Div. of Environmental Sanitation
	Water Pollution Control Commission * State Department of Health Building Campus, University of Minnesota Minneapolis 14, Minn.	R. N. Barr, M.D. Secretary
Mississippi	State Board of Health * State Board of Health Building P. O. Box 1700 Jackson 5, Miss.	A. L. Gray, M.D. Secretary and Executive Officer J. E. Johnston Director, Division of Sanitary Engineering
Missouri	State Water Pollution Board * 112 West High Street Jefferson City, Mo.	Jack K. Smith Executive Secretary
	State Dept. of Public Health and Welfare Division of Health Section of Environmental Health Services State Office Building Jefferson City, Mo.	A. W. Happy, Jr. Director, Section of Environmental Health Services
Montana	State Board of Health * Division of Environmental Sanitation Laboratory Building Helena, Mont.	G. D. Carlyle Thompson, M.D. Executive Officer and Secretary C. W. Brinck Director, Division of Environmental Sanitation
Nebraska	Department of Health * State Capitol Building Lincoln 9, Nebr.	E. A. Rogers, M.D. Director of Health
	Division of Sanitation State Dept. of Health State House Station, Box 4757 Lincoln 9, Nebr.	Ted A. Filipi Director

* Designated by the Public Health Service to receive Federal water pollution control grants.

Nevada	State Department of Health * Carson City, Nev.	D. J. Hurley, M.D. State Health Officer
	Division of Public Health Engineering State Department of Health 755 Ryland Street Reno, Nev.	W. W. White Director
New Hampshire	Water Pollution Commission * 61 S. Spring Street Concord, N. H.	William A. Healy Technical Secretary
New Jersey	State Department of Health * 129 E. Hanover Street Trenton 25, N. J.	Roscoe P. Kandle, M.D. State Commissioner of Health
	Division of Environmental Sanitation State Department of Health 65 Prospect Street Trenton 7, N. J.	Alfred H. Fletcher Director
New Mexico	New Mexico Department of Public Health * Santa Fe, N. Mex.	S. J. Leland, M.D. Director of Public Health
	Environmental Sanitation Services State Department of Public Health P. O. Box 711 Sante Fe, N. Mex.	Charles G. Caldwell Director
New York	State Department of Health * 84 Holland Avenue Albany 8, N. Y.	Herman E. Hilleboe, M.D. Commissioner of Health Charles G. Caldwell Director, Environmental Sanitation Services
North Carolina	Division of Sanitary Engineering State Board of Health North McDowell Street Raleigh, N. C.	J. M. Jarrett Director
	State Stream Sanitation Committee * State Dept. of Water Resources North McDowell Street Raleigh, N. C.	Earl C. Hubbard Director and Secretary
North Dakota	State Department of Health * Capitol Building Bismarck, N. Dak.	W. Van Heuvelen Executive Officer

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Ohio	Water Pollution Control Board * 306 Ohio Departments Building Columbus 15, Ohio	Ralph E. Dwork, M.D. Chairman
	State Department of Health Ohio Departments Building Columbus 15, Ohio	George Eagle Chief Sanitary Engineer
Oklahoma	State Department of Health * 3400 Block of North Eastern Oklahoma City 5, Okla.	Kirk T. Mosley, M.D. Commissioner of Health Harold L. Malone Director, Division of Sanitary Engineering
Oregon	State Board of Health * 1400 S. W. 5th Avenue Portland 1, Ore.	Richard H. Wilcox, M.D. State Health Officer
	Division of Sanitation and Engineering State Board of Health P. O. Box 231 Portland 7, Ore.	C. M. Everts, Jr. Director
Pennsylvania	Sanitary Water Board * Pennsylvania Department of Health State Capitol Health and Welfare Building Harrisburg, Pa.	Charles L. Wilbar, Jr., M.D. Chairman
	Bureau of Environmental Health State Department of Health P. O. Box 90 Harrisburg, Pa.	Karl M. Mason Director
Puerto Rico	Department of Health * Ponce de Leon Avenue San Juan 18, Puerto Rico	Guillermo Arbona, M.D. Secretary of Health
	Division of Sanitation Commonwealth of Puerto Rico Department of Health San Juan 18, Puerto Rico	Rafael L. Ocasio Chief
Rhode Island	Department of Health * State Office Building Providence 3, R. I.	Joseph E. Cannon, M.D. Director of Health
	Division of Sanitary Engineering State Department of Health 335 State Office Building Providence 2, R. I.	W. J. Shea Chief
South Carolina	State Water Pollution Control Authority * Room 417, Wade Hampton Building Columbia 1, S. C.	W. T. Linton Executive Director

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South Dakota	Committee on Water Pollution * State Capitol Pierre, S. Dak.	Charles E. Carl Secretary and Executive Officer
Tennessee	Division of Sanitary Engineering State Dept. of Public Health Cordell Hull Building Nashville 3, Tenn.	Julian R. Fleming Director
	Stream Pollution Control Board * Cordell Hull Building Sixth Avenue, North Nashville 3, Tenn.	S. Leary Jones Director
Texas	State Department of Health * 1100 W. 49th Street Austin 5, Tex.	J. E. Peavy, M.D. Commissioner of Health
	Division of Sanitary Engineering State Department of Health Austin 1, Tex.	G. R. Herzik Director
	Division of Water Pollution Control State Department of Health Austin 1, Tex.	David F. Smallhorst Director
Utah	Water Pollution Control Board * 45 S. Fort Douglas Boulevard Salt Lake City 13, Utah	Lynn M. Thatcher Executive Secretary
Vermont	State Water Conservation Board * State Office Building Montpelier, Vt.	R. W. Thieme Commissioner
	Bureau of Environmental Sanitation State Department of Health 115 Colchester Avenue Burlington, Vt.	E. L. Tracy Chief
Virginia	State Water Control Board * 415 West Franklin Street Richmond 20, Va.	A. H. Paessler Executive Secretary
	Division of Engineering State Department of Health 12th and Bank Streets Richmond 19, Va.	E. C. Meredith Director
Virgin Islands	Virgin Islands Department of Health * Charlotte Amalie St. Thomas, V. I.	Melvin H. Evans, M.D. Commissioner of Health
Washington	State Pollution Control Commission * 224 Old Capitol Building Olympia, Wash.	Wallace W. Bergerson Director

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	Division of Engineering and Sanitation State Department of Health 1523 Smith Tower Seattle 4, Wash.	Emil C. Jensen Chief
West Virginia	State Water Resources Commission * 1709-A Washington Street, East Charleston 1, W. Va.	Bern Wright Secretary
	Division of Sanitary Engineering State Department of Health 1800 Washington Street, East Charleston 5, W. Va.	J. H. Millar Director
Wisconsin	State Committee on Water Pollution * State Office Building Madison 2, Wis.	T. E. Wisniewski Director
	State Board of Health Room 453, State Office Building Madison 2, Wis.	O. J. Muegge Director of Environmental Sanitation
Wyoming	State Department of Public Health * State Office Building Cheyenne, Wyo.	James W. Sampson, M.D. Director of Public Health
	Division of Environmental Sanitation State Department of Public Health State Office Building Cheyenne, Wyo.	Arthur E. Williamson Director

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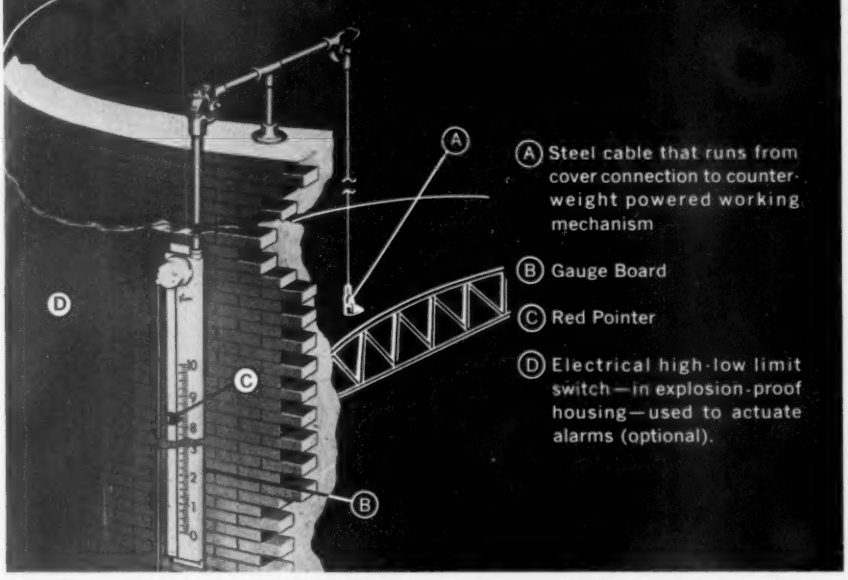
INTERSTATE WATER POLLUTION CONTROL AGENCIES

COOPERATING STATES	AGENCY AND ADDRESS	OFFICIAL AND TITLE
Illinois Missouri	Bi-State Development Agency 915 Olive Street St. Louis 1, Mo.	Leif J. Sverdrup Chairman
Delaware New Jersey New York Pennsylvania	Interstate Commission on the Delaware River Basin Suburban Station Building Philadelphia 3, Pa.	James H. Allen Executive Secretary
District of Columbia Maryland Pennsylvania Virginia West Virginia	Interstate Commission on the Potomac River Basin Transportation Building 815 17th Street, N.W. Washington 6, D. C.	Ellis S. Tisdale Director
Connecticut New Jersey New York	Interstate Sanitation Comm. 10 Columbus Circle New York 19, N. Y.	Thomas R. Glenn, Jr. Director and Chief Engineer
California Oregon	Klamath River Compact Commission P. O. Box 388 Sacramento 5, Calif.	A. E. Kuiper Executive Secretary
Connecticut Maine Massachusetts New Hampshire New York Rhode Island Vermont	New England Interstate Water Pollution Control Comm. 73 Tremont Street Boston 8, Mass.	Joseph C. Knox Secretary
Illinois Indiana Kentucky Ohio Pennsylvania New York Virginia West Virginia	Ohio River Valley Water Sanitation Commission 414 Walnut Street Cincinnati 2, Ohio	Edward J. Cleary Executive Director and Chief Engineer

VAREC INDICATOR

A SIMPLE, ACCURATE METHOD FOR INDICATING DIGESTER COVER POSITION


A
D
C
B
Ⓐ Steel cable that runs from cover connection to counter-weight powered working mechanism
Ⓑ Gauge Board
Ⓒ Red Pointer
Ⓓ Electrical high-low limit switch—in explosion-proof housing—used to actuate alarms (optional).

Varec's economical gauge board indicator accurately gauges the movement of floating cover digesters with a simple working mechanism... displays readings on a 12-foot, easy-to-read anodized aluminum gauge board installed directly outside the digester.

The calibrated gauge board shows measurements in feet and inches... has a 10-foot range with an extra 2 feet of pointer measurement for greater cover or overflow travel. It provides 'quick-at-a-glance' reading with a bright red pointer that contrasts sharply against the white aluminum board and large, black numerals. All parts are ruggedly constructed and the working mechanism is enclosed in a protective housing.

VAREC OFFERS POSITION INDICATORS FOR ALL DIGESTER COVER NEEDS...

Other Varec cover position indicators include a dial type indicator that registers indication within a 10-foot range on a large, easily read dial and can be equipped with alarm switches. And, for remote control reading, Varec provides a highly-accurate gauge head indicator that delivers gauging accuracy to ½ inch... adapts for use with electrical or pneumatic remote reading or control equipment.

For complete information on all Varec digester cover position indicators, write for Varec Catalog No. S-4, Dept. JWP-1221-S

"Varec"
TRADE ® MARK

THE VAPOR RECOVERY SYSTEMS COMPANY
2820 North Alameda Street • Compton, California
Branches and Representatives in Principal Cities

WATER POLLUTION CONTROL PRODUCT GUIDE

This list of products and services is offered as an information aid. The list was derived by solicitation from those firms listed. The JOURNAL will make every effort to keep this list current with the help of Associate Members and advertisers. All Associate Members and all advertisers for the past year are included. Many of the services and products are advertised in this issue. For an alphabetical listing see Index to Advertisers in back of JOURNAL. Write to the Federation office for complete address and representative.

Aerators (*also see* Diffusers, Air)
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Infilco Inc.
Link-Belt Co.
Pacific Flush Tank Co.
Permutit Co., Div. of Pfaudler Permutit Inc.
Smith & Loveless
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.
Yeomans Brothers Co.
Zimmer & Francescon

Agitators
Link-Belt Co.

Air Cleaning Equipment
Westinghouse Electric Corp.

Air Compressors (*also see* Blowers, Compressors, and Fans)
Chicago Pump Co.
Fairbanks, Morse & Co.
Komline-Sanderson Engr. Corp.
Worthington Corp.
Yeomans Brothers Co.

Air Diffusers (*see* Diffusers, Air)

Asbestos Cement Pipe Products
Filtration Equipment Corp.
Industrial Materials Co.
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Ash Handling Equipment
Link-Belt Co.

Bearings
Link-Belt Co.

Bins, Storage (*see* Tanks)

Biologists (*see* Professional Services, elsewhere in this issue)

Blowers (*also see* Air Compressors, Compressors, and Fans)
Chicago Pump Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Sutorbilt Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Boilers
Combustion Engineering, Inc.

Building Maintenance Equipment and Supplies
Homestead Valve Mfg. Co.

Cast Iron Pipe Products
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Industrial Materials Co.
U. S. Pipe & Foundry Co.
R. D. Wood Co.

Cement (*see* Concrete)

Centrifuging Equipment
Bird Machine Co.
Permutit Co., Div. of Pfaudler Permutit Inc.

Chains
Chain Belt Co.
Link-Belt Co.

Chemical Feed Equipment
Builders-Providence Div., B-I-F Industries
Capital Controls Co., Inc.
Eimco Corp.
Fischer & Porter Co.
Graver Water Conditioning Co.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Link-Belt Co.
Omega Div., B-I-F Industries
Permutit Co., Div. of Pfaudler Permutit Inc.
Proportioneers Div., B-I-F Industries
Wallace & Tiernan Inc.

Chemicals
Dow Chemical Co.
Fisher Scientific Co.
General Chemical Div., Allied Chemical Corp.
Glenn Chemical Co.
Hach Co.
Tennessee Corp.

Chemists (*see* Professional Services, elsewhere in this issue)

Chlorination Equipment
Builders-Providence Div., B-I-F Industries
Capital Controls Co., Inc.
Fischer & Porter Co.
Graver Water Conditioning Co.
Wallace & Tiernan Inc.
Zimmer & Francescon

Clarifier Equipment (*also see* Sedimentation Equipment)
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Link-Belt Co.
Permutit Co., Div. of Pfaudler Permutit Co.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Clay Pipe Products
W. S. Dickey Clay Mfg. Co.
Industrial Materials Co.
National Clay Pipe Mfrs., Inc.
Robinson Clay Product Co.

Coatings and Linings (Pipe and Tank)
Amercoat Corp.
Centriline Corp.
Inertol Co., Inc.
Koppers Co., Inc.
Lock Joint Pipe Co.
National Water Main Cleaning Co.
Perry-Austen Mfg. Co.
Stebbins Engr. & Mfg. Co.

Comminutors (*also see* Shredders and Grinders)
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Infilco Inc.
Jeffrey Mfg. Co.
Smith & Loveless
Walker Process Equipment Inc.
Worthington Corp.

Compressors
Chicago Pump Co.
Fairbanks, Morse & Co.
Komline-Sanderson Engr. Corp.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Worthington Corp.
Yeomans Brothers Co.

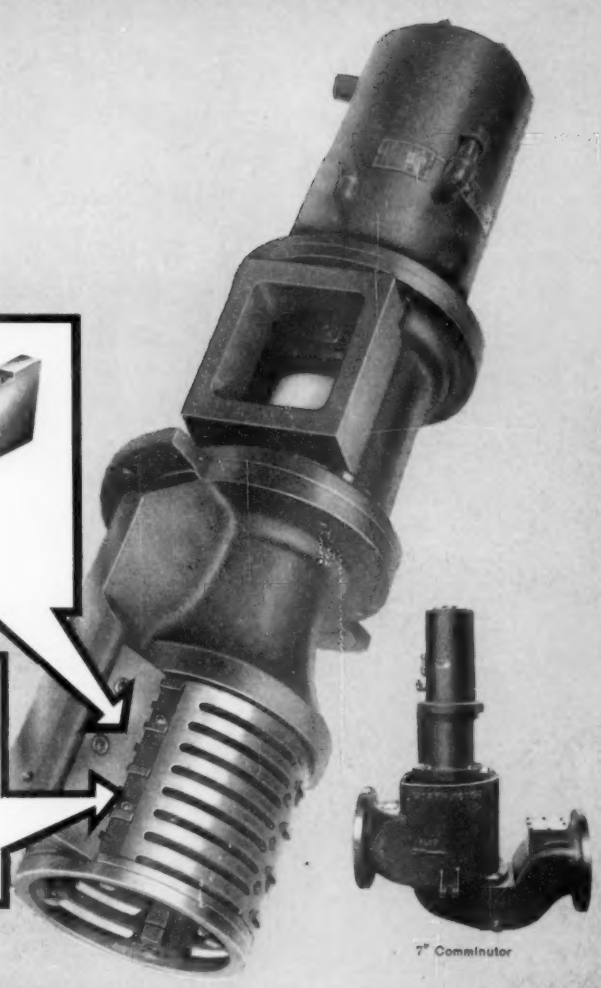
Computers
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.

Concentrators (*see* Sludge Concentrators)

Concrete
Portland Cement Assn.

Concrete Pipe Products
American Concrete Pressure Pipe Assn.
American-Marietta Co.
Industrial Materials Co.
Lock Joint Pipe Co.
Price Brothers Co.

Construction Equipment
Chain Belt Co.
Eimco Corp.
Worthington Corp.



CUTTER BARS SERVICE FASTER— DOUBLE COMMINUTOR TOOTH LIFE

In a Worthington comminutor, all teeth are mounted as units called "cutter bars." This makes servicing much faster and doubles tooth life. Here's why . . .

As you can see for the 7″ comminutor above, there are just one stationary and four rotating bars. Thus all teeth are removed by releasing just five cutter bars, instead of many teeth one by one. There is far less cutter adjustment, too. Note also that the 7″ comminutor rotating cutter bars are reversible. Thus you get double the cutter life until resharpening. And resharpening is faster, too, because cutter bars are much easier to handle than separate teeth.

And here are three other exclusive Worthington 7″ comminutor features (compare them): 33⅓% more power through using a ⅓ hp motor; greater capacity . . . up to .45 mgd; and easier installation with flanged or bell and spiggot construction.

Worthington's 7″ comminutor is ideal for packaged treatment plants and unattended stations. Larger Worthington comminutors with equally desirable advantages handle flows up to 26 mgd. For more information, write Worthington Corporation, Department 105-7, Harrison, N. J. In Canada, Worthington (Canada) Ltd., Brantford, Ontario.

WORTHINGTON

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Chicago Pump Co.
Fischer & Porter Co.
Foxboro Co.
General Electric Co.
Homestead Valve & Meter Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Ohmart Corp.
Penn Instruments Div., Penn Meter Co.
Permutit Co., Div. of Pfaudler Permutit Co. Inc.
Rockwell Mfg. Co.
Wallace & Tiernan Inc.
Westinghouse Electric Corp.
Worthington Corp.

Conveyors
American Well Works
Chain Belt Co.
Chicago Pump Co.
Jeffrey Mfg. Co.
Link-Belt Co.
Stuart Corp.

Corrosion Protection
Amercoat Corp.
Chicago Pump Co.
Inertol Co., Inc.
Johns-Manville Sales Corp.
Koppers Co., Inc.
Lock Joint Pipe Co.
Perry-Austen Mfg. Co.
A. O. Smith Corp.
Stebbins Engr. & Mfg. Co.
Wallace & Tiernan Inc.

Couplings
Link-Belt Co.

Diffusers, Air (*also see* Aerators)
Alpha Ltd. (Switzerland)
American Well Works
Carborundum Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.
Zimmer & Francescon

Diffusers, Gas (*also see* Aerators)
American Well Works
Carborundum Co.
Chicago Pump Co.
Eimco Corp.
Infilco Inc.
Walker Process Equipment Inc.
Yeomans Brothers Co.

Digestion Tank Equipment
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Gorman-Rupp Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
A. O. Smith Corp.
Smith & Loveless
Varec, Inc.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Distributors, Rotary
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Smith & Loveless
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Dryers
Alpha Ltd. (Switzerland)
Combustion Engineering, Inc.
Eimco Corp.
Hardinge Co., Inc.
Komline-Sanderson Engr. Corp.
Link-Belt Co.
Nichols Engr. & Research Corp.
Stuart Corp.

Ejectors
Komline-Sanderson Engr. Corp.
Smith & Loveless
Tex-Vit Mfg. Co.
Yeomans Brothers Co.

Engineers (*see* Professional Services, elsewhere in this issue)

Engines (Sludge Gas and Petroleum Fuels)
Fairbanks, Morse & Co.
Waukesha Motor Co.
Worthington Corp.

Fans (*also see* Air Compressors, Blowers, and Compressors)
Chicago Pump Co.
Lakeside Engineering Corp.
Westinghouse Electric Corp.

Filter Equipment, Trickling
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
W. S. Dickey Clay Mfg. Co.
Dorr-Oliver Inc.
Dow Chemical Co.
Eimco Corp.
Filtration Equipment Corp.
Industrial Materials Co.
Infilco Inc.
Keasbey & Mattison Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Nichols Engr. & Research Corp.
Pacific Flush Tank Co.
Smith & Loveless
Trickling Filter Floor Inst.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Filter Materials
Carborundum Co.
Filtration Equipment Corp.
Glenn Chemical Co.
Graver Water Conditioning Co.
Industrial Materials Co.
Johns-Manville Sales Corp.

Filters, Diatomaceous Earth
Graver Water Conditioning Co.
Yeomans Brothers Co.

Filters, Vacuum (*also see* Vacuum Filters)
Bird Machine Co.
Dorr-Oliver Inc.
Eimco Corp.
Proportioneers Div., B-I-F Industries

Flocculating Equipment
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Lakeside Engineering Corp.
Link-Belt Co.
Permutit Co., Div. of Pfaudler Permutit Inc.
Stuart Corp.
Walker Process Equipment Inc.
Zimmer & Francescon

Flotation Equipment
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Komline-Sanderson Engr. Corp.
Yeomans Brothers Co.

Flow Measurement
Filtration Equipment Corp.
F. B. Leopold Co., Inc.
Penn Instruments Div., Penn Meter Co.

Gas Control Equipment
Alpha Ltd. (Switzerland)
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Foxboro Co.
Homestead Valve Mfg. Co.
Pacific Flush Tank Co.
Penn Instruments Div., Penn Meter Co.
Rockwell Mfg. Co.
Varec, Inc.
Walker Process Equipment Inc.
Zimmer & Francescon

Gas Diffusers (*see* Diffusers, Gas)

Gas Holders, Boilers, and Appurtenances
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Johns-Manville Sales Corp.
Walker Process Equipment Inc.

Gaskets
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Gates
Armco Drainage & Metal Products, Inc.
Filtration Equipment Corp.
Industrial Materials Co.
Snow Gates & Valves, Inc.

Generators
Fairbanks, Morse & Co.
General Electric Co.
Westinghouse Electric Corp.
Worthington Corp.

Grinders (*also see* Shredders and Grinders)
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Yeomans Brothers Co.

Grit Collection and Conditioning Equipment
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Link-Belt Co.
Stuart Corp.
Walker Process Equipment Inc.
Zimmer & Francescon

HOLDS TIGHT AGAINST SEVERE VIBRATION

W-K-M's Non-Lubricated Eccentric Plug Valve

This valve is located close to a piston pump handling a heavy and abrasive sewage sludge. Since it was installed more than a year ago in this modern sewage disposal plant, it has made a record of perfect performance — *no effects from severe vibration, no leaks, no maintenance, no repairs.*

Severe vibration was destructive to all previous valves which — frequently and at random — worked open or closed causing almost perpetual stem and line leakage. Constant attention and maintenance were required.

W-K-M's Eccentric Plug Valve is ideal where such severe conditions are involved. Its unique design allows it to maintain its open or closed position regardless of vibration or other shocks. The resilient elastomer bonded to the plug efficiently resists the abrasive action of sludges or other solid-bearing liquids.

Write for full information, P. O. Box 1317, Houston, Texas.

When So Much Depends on a Valve

. . . *Specify* W-K-M

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W-K-M
DIVISION

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Grounds Maintenance Equipment and Supplies
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Heating Equipment for Digesters and Buildings
Alpha Ltd. (Switzerland)
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
General Electric Co.
Infilco Inc.
Link-Belt Co.
Pacific Flush Tank Co.
Walker Process Equipment Inc.

Incinerators
Combustion Engineering, Inc.
Nichols Engr. & Research Corp.
Walker Process Equipment Inc.
Zimpro, Div. of Sterling Drug Inc.

Insect Control
Glenn Chemical Co.

Inspection, Sewers
Centriline Corp.
Inspectoline Inc.
National Water Main Cleaning Co.

Instruments, Recording and Control (*also see* Controls and Recorders)
Builders-Providence Div., B-I-F Industries
Fischer & Porter Co.
Fisher Scientific Co.
Foxboro Co.
General Electric Co.
Hach Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Ohmart Corp.
Penn Instruments Div., Penn Meter Co.
Rockwell Mfg. Co.
Wallace & Tiernan Inc.
Westinghouse Electric Corp.

Ion-Exchange Equipment
Permutit Co., Div. of Pfaudler Permutit Inc.
A. O. Smith Corp.

Jointing Materials
American Concrete Pressure Pipe Assn.
W. S. Dickey Clay Mfg. Co.
Keasbey & Mattison Co.
National Clay Pipe Mfrs., Inc.
Perry-Austen Mfg. Co.
Robinson Clay Product Co.
Stebbins Engr. & Mfg. Co.

Joints, Mechanical
American Cast Iron Pipe Co.
W. S. Dickey Clay Mfg. Co.
Johns-Manville Sales Corp.
Robinson Clay Product Co.
Smith-Blair, Inc.
U. S. Pipe & Foundry Co.

Laboratory Equipment and Supplies
Filtration Equipment Corp.
Fisher Scientific Co.
General Chemical Div., Allied Chemical Corp.
Hach Co.
Stuart Corp.

Lift Stations
Davco Corp.
Smith & Loveless
Tex-Vit Mfg. Co.
Yeomans Brothers Co.

Lighting Fixtures
General Electric Co.
Westinghouse Electric Corp.

Lubricants
Homestead Valve Mfg. Co.
Johns-Manville Sales Corp.

Manhole and Inlet Castings
American-Marietta Co.
Varec, Inc.

Masonry Building Materials
American-Marietta Co.
Portland Cement Assn.
Price Brothers Co.

Meter Boxes
Johns-Manville Sales Corp.

Meters (Sewage, Sludge, Water, Air, and Gas)
Builders-Providence Div., B-I-F Industries
Ralph B. Carter Co.
Filtration Equipment Corp.
Foxboro Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Penn Instruments Div., Penn Meter Co.
Rockwell Mfg. Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Simplex Valve and Meter Co.
Worthington Corp.

Mixing Devices
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.

Motors
Chicago Pump Co.
Fairbanks, Morse & Co.
General Electric Co.
Link-Belt Co.
A. O. Smith Corp.
Westinghouse Electric Corp.
Worthington Corp.

Nozzles, Spray
Spray Engineering Co.

Odor Control Materials
Airkem, Inc.
Tennessee Corp.
Wallace & Tiernan Inc.

Odor Counteractants
Airkem Inc.

Package Treatment
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Infilco Inc.
Municipal Service Co.
Smith & Loveless
Walker Process Equipment Inc.
Yeomans Brothers Co.

Packing
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Paints and Protective Coatings
Amercoat Corp.
Inertol Co., Inc.
Koppers Co., Inc.
Perry-Austen Mfg. Co.
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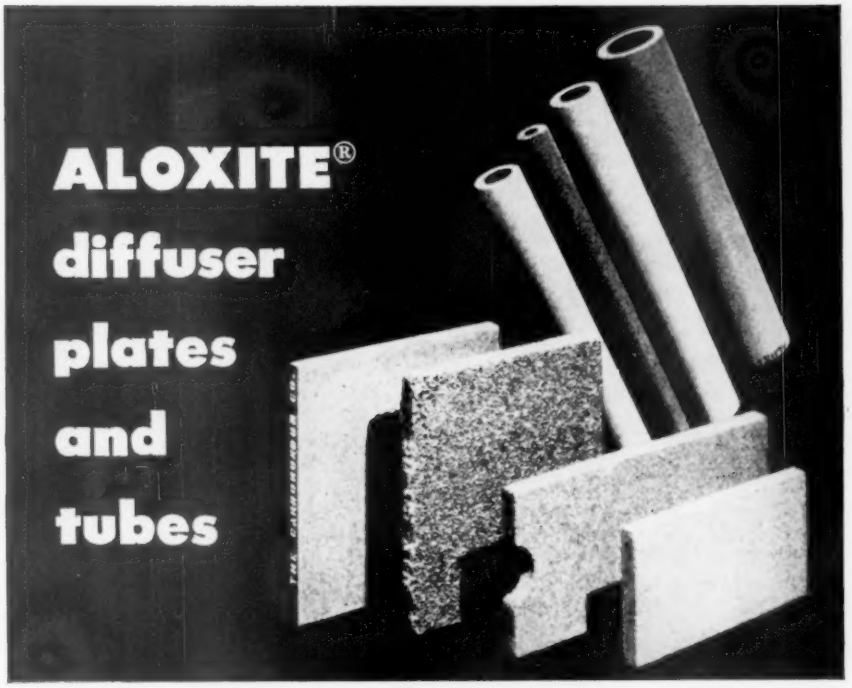

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PROCEEDINGS OF MEMBER ASSOCIATIONS

NORTH CAROLINA WATER POLLUTION CONTROL ASSOCIATION

The 40th Annual Joint Convention of the North Carolina Sewage and Industrial Waste Association and the North Carolina Section of the American Water Works Association was held at the Robert E. Lee Hotel, Winston-Salem, N. C., Nov. 9–11, 1960.

The highlight of Wednesday afternoon was the field trip to Winston-Salem's new waste treatment plant.

Before the business meeting on Friday morning, three interesting films were shown: "New Sewers for Old," "Chlorine Safety," and "Asbestos Cement Pipe Water Mains."

At the annual business meeting the Association voted to change its name to the North Carolina Water Pollution Control Association. Lee S. Dukes, Jr., Federation Director, gave a beautifully illustrated report of the recent convention in Philadelphia. It was warmly enjoyed by all in attendance. At the luncheon on Thursday, Ralph E. Fuhrman, WPCF Executive Secretary, gave a Federation progress report.

Papers of particular interest to those in the wastewater field were:

"Water and Sewer Operations in Winston-Salem During the Flying 50's," by Stanford E. Harris, Superintendent, Department of Water and Sewerage, Winston-Salem.

(*Continued on page 525a*)

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"Studies of Recirculating Effluent Of Trickling Filters," by Lee S. Dukes, Jr., Water Department, Charlotte.

"Contact Stabilization and Long-Term Aerobic Stabilization," by Tom Alspaugh, Chemist, Cone Mills, Greensboro.

The following officers were elected to serve for 1960–61:

Chairman: L. P. Bloxham, Greenville.
Vice-Chairman: J. H. Henderlite, Charlotte.
Director: Lee S. Dukes, Jr., Charlotte.
Secretary-Treasurer: T. Z. Osborne, Greensboro.

T. Z. Osborne
Secretary-Treasurer

SOUTH CAROLINA WATER AND SEWAGE WORKS ASSOCIATION

The Annual Meeting of the South Carolina Water and Sewage Works Association, Sewage Section, was held at the Jefferson Hotel, Columbia, S. C., Nov. 4, 1960. The meeting was judged an outstanding success with a record attendance of 71 members and guests.

The program included outstanding papers by George Hutto, Mooresville Mills, Mooresville, N. C.; T. A. Alspaugh, Cone Mills, Greensboro, N. C.; and Chester Hatch, Consulting Engineer, Greenville. Huger Sinkler, a bond attorney, Charleston, discussed utility financing. The presentation of a film, "Pennies for Health," rounded out one of the best programs the Association has had.

Officers for the year 1960–61 are:

Chairman: J. D. Lesslie, Fort Mill.
Vice-Chairman: H. H. Connelly, Newberry.
Director: J. D. Lesslie, Fort Mill.
Secretary: Robert N. Bowen, Columbia.
Treasurer: T. P. Anderson, Columbia.

Robert N. Bowen
Secretary

(*Continued on page 529a*)

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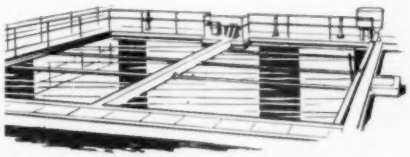

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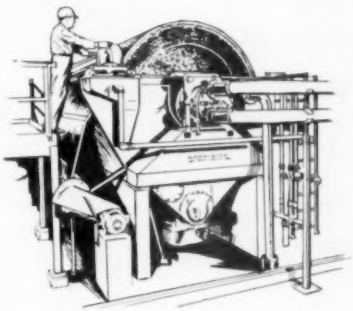

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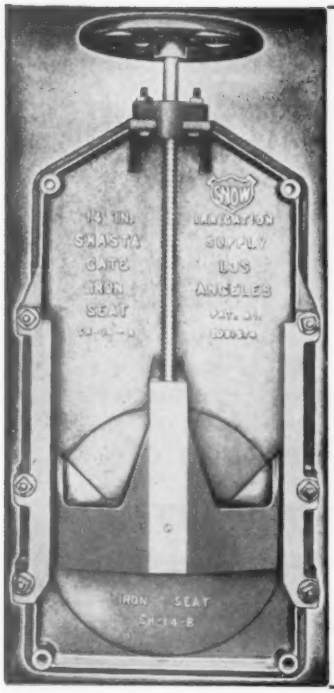

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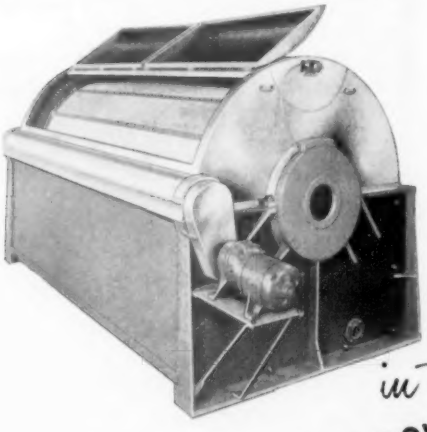

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MISSISSIPPI WATER POLLUTION CONTROL ASSOCIATION

The 4th Annual Meeting of the Mississippi Sewage and Industrial Wastes Association was held at the Robert E. Lee Hotel, Jackson, Mar. 10, 1961. Attendance at the meeting was approximately 100, with a number of industrial waste men present. Wives of members were invited for the first time, and their attendance was excellent.

By unanimous vote, the name of the Association was changed to the Mississippi Water Pollution Control Association.

Harry E. Schlenz, Federation Vice-President, was a speaker at both the luncheon and the business session. He discussed Federation activities, the Policy Statement, and the Water Pollution Control Conference of last December. He also presented the Bedell Award to J. E. Johnston, Director, Division of Sanitary Engineering, State Board of Health, Jackson.

Papers of interest were:

"Radioactive Wastes in Water," by Dade W. Moeller, Chief, Radiological Health Training Activities, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

"Lagoon Treatment of Meat Packing Plant Wastes," by F. W. Sollo, Research Chemist, Illinois State Water Survey, Urbana, Ill.

"Industrial Waste Disposal Problems," by Frank J. Coogan, Engineer, International Paper Co., Mobile, Ala.

"Water is Where We Protect It," by A. L. Gray, Executive Officer, State Board of Health, Jackson.

Officers elected or re-elected at the meeting to serve for the coming year are:

President: Neil G. McMahon, Jackson.
Vice-President: John H. Teunisson, Jr., Greenville.

(*Continued on page 531a*)

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PUERTO RICO WATER AND SEWAGE WORKS ASSOCIATION

The Puerto Rico Water and Sewage Works Association held one of its most interesting meetings at the Condado Beach Hotel, San Juan, Puerto Rico, Feb. 24, 1961. Attendance totaled 94, including 25 ladies. Guillermo Arbona, Secretary of the Department of Health of the Commonwealth of Puerto Rico, was the distinguished guest.

Everyone enjoyed the dinner which was served in the Governor's Room of the hotel. Israel Rivera-Marini, President of the Association, introduced Dr. Arbona as the speaker for the occasion. During his speech, Dr. Arbona mentioned the close relationship existing between sanitary engineering and some of the programs under way in his department.

Other distinguished guests were Adalberto Bogel, World Health Organization, United Nations; and Juan Labadie Eurite, Executive Director, Puerto Rico Aqueduct and Sewer Authority.

After Dr. Arbona's talk, there was a show and dancing in the Fiesta Room of the hotel.

ROBERT J. AULD
Secretary-Treasurer

ARKANSAS WATER AND SEWAGE CONFERENCE

The 30th Annual Arkansas Water and Sewage Conference and Short School were held at the Marion Hotel, Little Rock, Ark., Mar. 20–22, 1961. Attendance at the meeting totaled 260.

Over 125 attended the Federation Luncheon on the first day of the Conference when registration was still in-

(*Continued on page 532a*)

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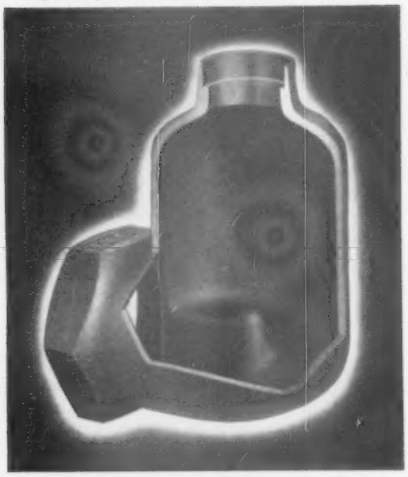

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complete. Harry E. Schlenz, Federation Vice-President, spoke on water pollution control and public relations, a challenge to the profession and the Federation. Preceding the Luncheon, there was a field trip to Little Rock's new sewage treatment plant.

The Monday afternoon session of the sewage section enjoyed two panel discussions. The first, "Sewer Main Extension Policies," included T. W. Clapham, Manager of the Sanitary Sewer System, Little Rock; Neal Thayer, Manager of the water and light plant, Jonesboro; and Walter Scales, Manager, Conway Water Co., Conway. The second panel on "Oxidation Ponds," had R. L. Yeatman, Engineer, Arkansas Water Pollution Control Commission, Little Rock, as moderator. The panel members and their topics of discussion were: "Design and Construction," by L. M. McGoodwin, Consulting Engineer, Fayetteville; "Biology," by J. B. Anderson, Director, Water Quality Section, HEW, Dallas, Tex.; and "Operation," by Jerome H. Svore, Regional Program Director, Water Supply and Pollution Control, HEW, Dallas, Tex.

At the business meeting the following officers were elected or reelected for 1961-62:

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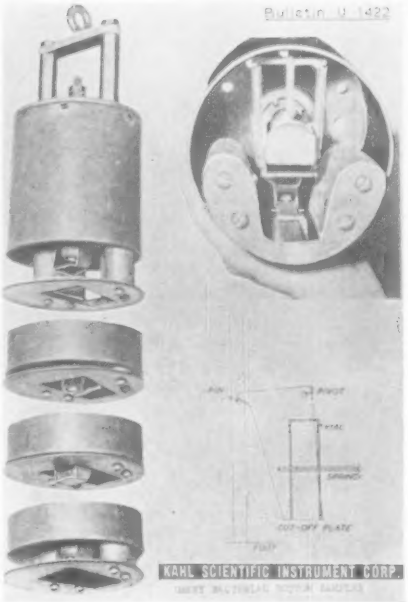

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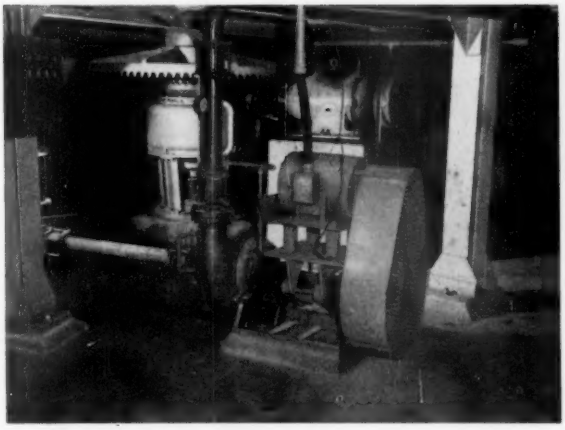

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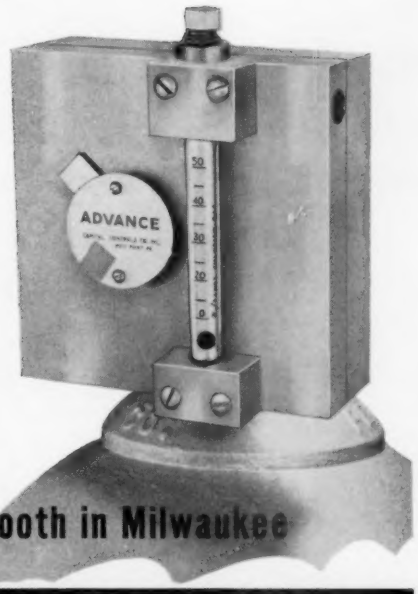

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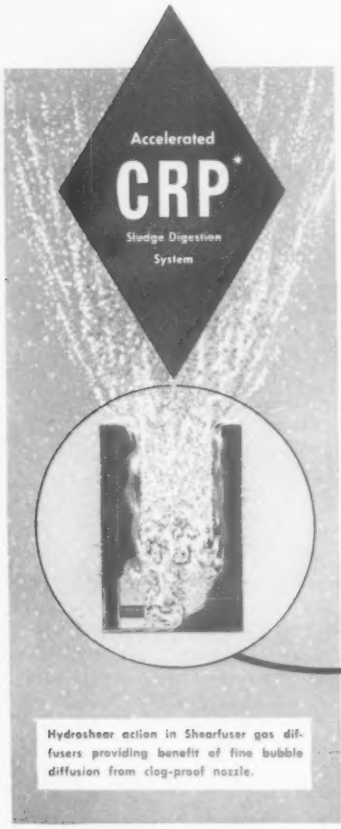

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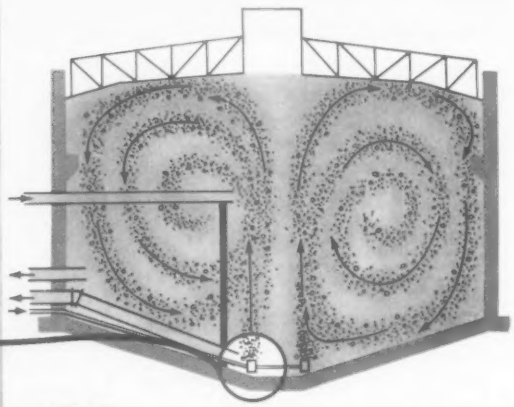

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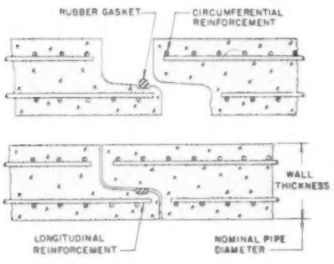

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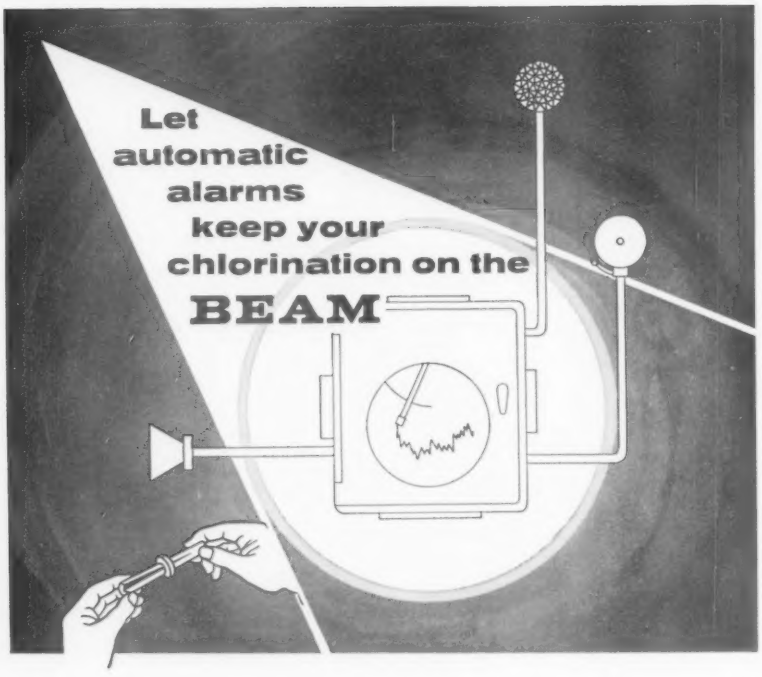

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